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ADVANCED AUTOMOTIVE POWER SYSTEM STRUCTURED VALUE ANALYSIS MODEL

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A model which will provide a tool in evaluating advanced low-emission power systems, and a basis for decisions relating to further development of candidate power systems is presented. The technique is quantitative and readily adaptable to the stage of a candidate's development. It relies primarily on engineering measurements and provides consistent repeatable results. It allows the use of expert value judgments as a valid part of the evaluation process. The parameters which, when measured, will provide the information needed to describe and adequately evaluate the candidate are listed, and the measurement scales and the rationale for the parameter selection are provided. The cost and economic factors critical to the evaluation of candidates are discussed. Consideration is given to the research and development costs, cost to the consumer, economic reallocation, and cost to governments. The analytical formulation of the model is addressed, including the value functions which relate the parameter measurements to a value to the user. Also included are value sets of parameters for eight evaluation categories: emissions, operating performance, acceptability, operating environment, safety, personnel and facilities, propulsion system technology and reliability and maintenance. A total value set is also presented. The results of the sensitivity analysis conducted on the model are also presented. A discussion of Structured Value Analysis and a description of the SVA computer program are appended.

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SECTION I

INTRODUCTION

This document presents the Structured Value Analysis (SVA) Model developed for the Division of Advanced Automotive Power Systems Development (DAAPSD), Environmental Protection Agency. The model will provide a tool ~~for DAAPSD to use~~ in evaluating advanced low-emission power systems, and a basis for decisions relating to further development of candidate power systems.

The Advanced Automotive Power System (AAPS) program is directed toward the "goal of producing an unconventionally power, virtually pollution free automobile within five years."* To achieve this goal, the AAPS program provides for the development of available candidate power systems from design into first generation hardware and then through a second generation system for demonstration before 1975. The AAPS program will result in the demonstration of two systems which will be able to compete technically, economically and commercially with the gasoline-fueled, spark-ignition, internal combustion engine.

In order to achieve this goal, a large number of AAPS candidates must be evaluated, with those holding the most promise proceeding into the full scale development program which will lead to successful demonstration by 1975. Throughout the program, the number of candidate propulsion systems must be progressively reduced. This requires that frequent formal reviews and evaluations be conducted in order to insure that those systems selected for development meet the emissions standards of the Clean Air Act and can compete technically and economically with the conventional automobile power system.

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*President Nixon's Message on Environment, February 10, 1970.

The technique for evaluating the AAPS candidates must be quantitative and readily adaptable to the stage of a candidate's development. In addition, the technique must rely primarily on engineering measurements and provide consistent repeatable results. Finally, the technique must allow the use of expert value judgments as a valid part of the evaluation process. The AAPS Structured Value Analysis model described in this report provides these necessary evaluation technique characteristics.

The first step in establishing an evaluation technique is to identify those parameters which, when measured, will provide the information needed to describe and adequately evaluate the AAPS candidate. Section 2.0 provides the list of the parameters, the measurement scales and the rationale for the parameter selection. The measurement scales are based principally on the DAAPSD Advanced Automotive Power System Program "Vehicle Design Goals - Six Passenger Automobile (Revision B-February 11, 1971," 11 pages) (Appendix I).

Section 3.0 presents a discussion of the cost and economic factors critical to the evaluation of AAPS candidates. Consideration is given to the research and development costs, cost to the consumer, economic reallocation, and cost to governments.

The analytical formulation of the AAPS Structured Value Analysis model is addressed in Section 4.0. Included are the value functions which relates the parameter measurements to a value to the user, the user in this case being DAAPSD acting as agent for the motoring public. Also included are value sets of parameters for eight evaluation categories: emissions, operating performance, acceptability, operating environment, safety, personnel and facilities, propulsion system technology and reliability and maintenance. Finally, a total AAPS value set is presented. This system value set will allow a composite value score over the eight evaluation categories to be assigned to an AAPS candidate.

Section 5.0 contains the results of the sensitivity analysis conducted on the SVA model. The parameters with the most influence on the value scores in each evaluation category are identified. Those parameters which have the least impact on value scores are also identified and are considered for deletion from the model.

A discussion of Structured Value Analysis and a description of the SVA computer program are contained in Appendix II.

SECTION II

EVALUATION PARAMETERS

2.0 INTRODUCTION

This section presents the preliminary list of parameters used to describe low emission advanced automotive power systems. The rationale for their selection and scales of measurement including the maximum and the minimum of the range are included.

The selection of the parameters was made independent of any particular advanced power system technology. As such, the parameters will be applicable to the evaluation of any candidate low emission power system in any stage of development. It should be recognized that it may not be feasible to get actual measurements for all parameters during the early phases of the Advanced Automotive Power System program, since many candidate systems will be in the "paper design" stage and "hard" test data will not be available. Therefore, it will be necessary to establish a measure of uncertainty for selected parameters where validated engineering data are not available.

The ranges of values for the parameters were based primarily on the Advanced Automotive Power System "Vehicle Design Goals - Six Passenger Automobile (Revision B - February 11, 1971 - 11 pages)." (Appendix I) The maximum and minimum data points are established for evaluation purposes only and should not be construed as goals. For example, the maximum values for several performance parameters represent maximum safety values; thus, actual performance above these maximums is not recommended (i.e., a maximum speed capability above 110 mph is considered dangerous).

The parameters have been divided into eight major categories as follows:

1. Emissions
2. Operating Performance
3. Acceptability
4. Operating Environment
5. Safety
6. Personnel and Facilities
7. Propulsion System Technical Characteristics
8. Reliability/Maintenance.

The remainder of this section presents descriptions of the individual parameters. The value judgment curves for the parameters are found in Section IV.

2.1 Emissions

2.1.1 Carbon Monoxide

CO is the most abundant and widely distributed gaseous pollutant, with the automobile causing approximately 90% of the total. Destruction of CO is almost entirely natural; however, the processes involved are poorly understood. The toxic effects of carbon monoxide on humans have been known and studied for some time. The primary effect is based on CO's strong affinity for hemoglobin, with which it combines much more readily than oxygen, to form carboxyhemoglobin. This reduces the capacity of the blood to transport oxygen from the lungs to the tissues of the body. The source of 90% of the carbon monoxide in the atmosphere is the exhaust of the internal combustion engine (ICE). Considerable progress has been made in recent years in reducing the CO emissions from the ICE. As a result carbon monoxide output from the average new vehicle has been reduced from 85+ grams/vehicle mile for uncontrolled vehicles to 34 grams/vehicle mile with the introduction of exhaust controls on the 1968 models.

A number of State and Federal automobile exhaust standards for CO emissions have been established by the Clean Air Act for 1975 model year vehicles. Considerable promise is shown in meeting most standards and goals through the use of alternative propulsion systems or advancing the state of the art in controlling CO emissions from the IC engine. Emission characteristics for a number of alternative propulsion systems and from a modified IC engine are compared to a number of goals and standards in Figure 1. For the purpose of evaluating advanced automotive propulsion system emissions, a range of 3.4 grams/vehicle mile to 4.5 grams/vehicle mile is chosen. (Curve 1.1)

2.1.2 Hydrocarbons

Hydrocarbons, parts of the fuel not burned in the normal IC engine combustion cycle, are released into the atmosphere. Approximately 50% of all hydrocarbons released into the air come from the IC engine. While no direct health effects have been shown for hydrocarbons in the atmosphere, they do have an indirect effect through their participation in photochemical reactions which result in the

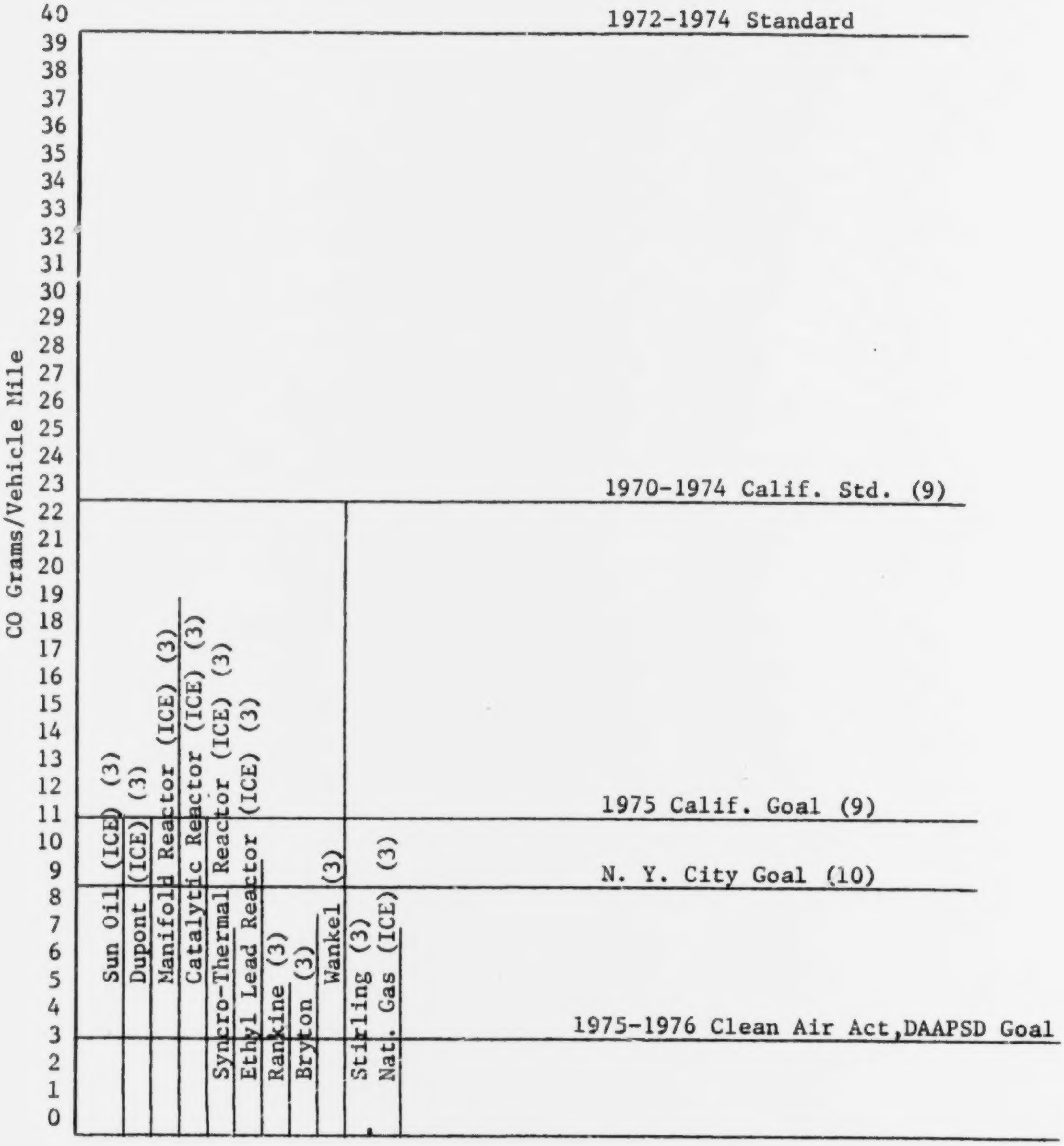

FIGURE 1

AUTOMOTIVE CO EMISSIONS AND STANDARDS

formation of smog which does produce plant damage, eye and respiratory tract irritation, and reduced visibility. Hydrocarbons are released into the atmosphere from three sources on the automobile: exhaust, 55%; fuel evaporation from the fuel tank and the carburetor, 20%; and crankcase blowby, 25%. The crankcase blowby was the first source of IC engine emission to be controlled. All new cars sold in this country after 1962 have crankcase blowby control devices, thus eliminating hydrocarbon emissions from this source. Reductions in hydrocarbon exhaust and evaporation emissions will further reduce hydrocarbon emissions to approximately 3.4 grams/vehicle mile for 1972 automobiles. This represents a 70% reduction compared with 1962 and earlier models without controls.

Further reductions in hydrocarbon emissions must be made since more stringent standards and goals have been established by state and Federal authorities. These standards and goals are shown in Figure 2. The goal of 0.41 grams/vehicle mile has been established by DAAPSD and the Clean Air Act for advanced automotive propulsion systems. Figure 2 also shows that many of these standards and goals are technically attainable through the use of alternative propulsion systems or a modified IC engine.

For the purpose of evaluating advanced automotive propulsion system emissions, a range of 0.3 grams/vehicle mile to 0.5 grams/vehicle mile has been chosen. (Curve 1.2)

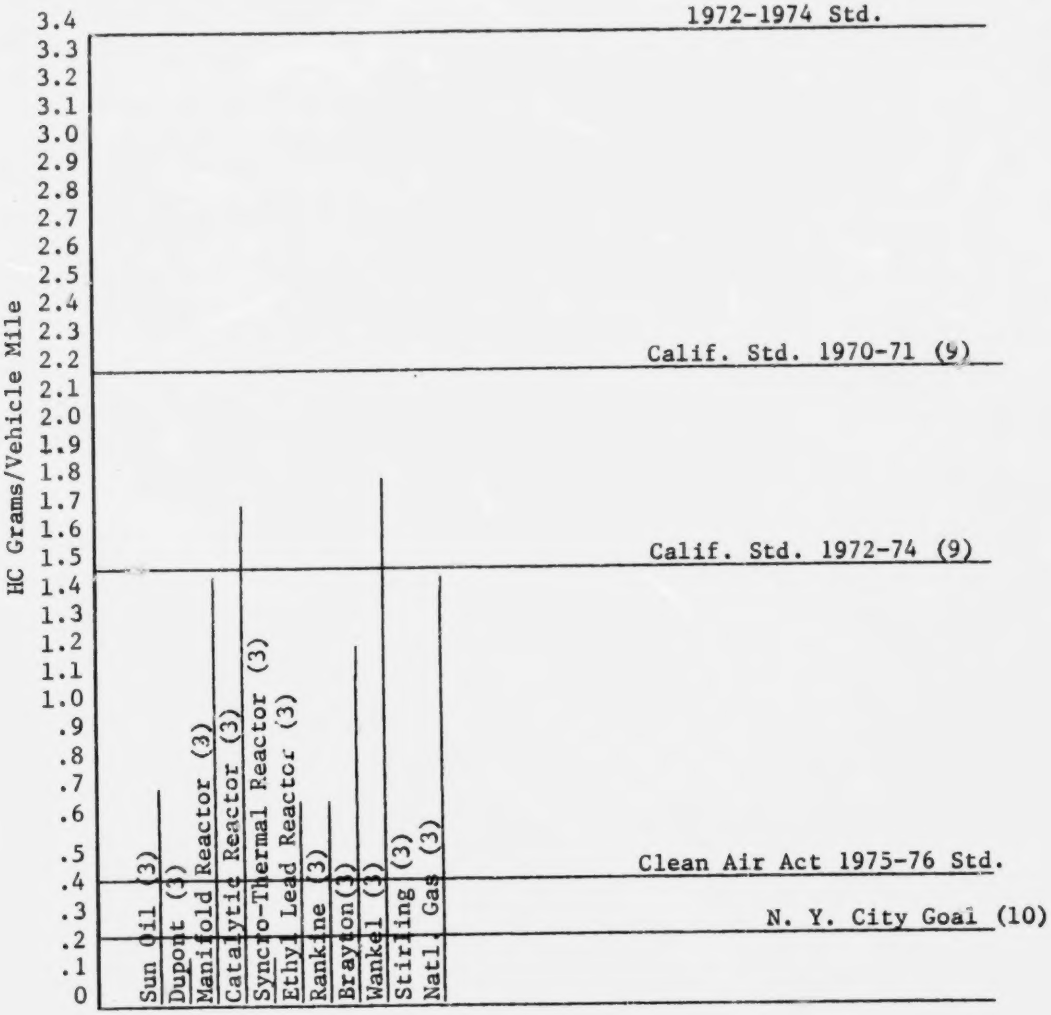

FIGURE 2

AUTOMOTIVE HC EMISSIONS AND STANDARDS

2.1.3 Oxides of Nitrogen

NO_x is also a product that forms from combustion, with the exhaust being the source for all automobile emissions. The oxides of nitrogen are major participants in the formation of photochemical smog with the most significant one being nitrogen dioxide (NO_2), a yellow brown gas, which significantly reduces atmospheric visibility at low concentrations. It is known to be toxic to man; however, the low concentrations which occur in the community atmosphere have not been identified as damaging to health.

NO_x has been the last of the major automotive pollutants to come under control. Control of NO_x was started on some 1970 model automobiles in order to meet the 1971 California Standard of 4 grams/vehicle mile. The Federal Standard of 3 grams/vehicle mile is to go into effect in 1973. Longer range goals have been established by Federal, State and Local Governments. Among these are:

a. 1973 California Standard - 1.3 grams/mile (reported as NO_2)

b. New York City - .9 grams/mile (reported as NO_2)

c. DAAPSD goal - .4 grams/mile (reported as NO_2)

d. Clean Air Act Standard 1976 - .4 grams/mile (reported as NO_2)

These standards are illustrated in Figure 3.

Research has established that NO_x emissions can be substantially reduced. The modified IC engine and alternative propulsion systems, as shown in Figure 3, offer considerable promise in meeting the established standards and goals.

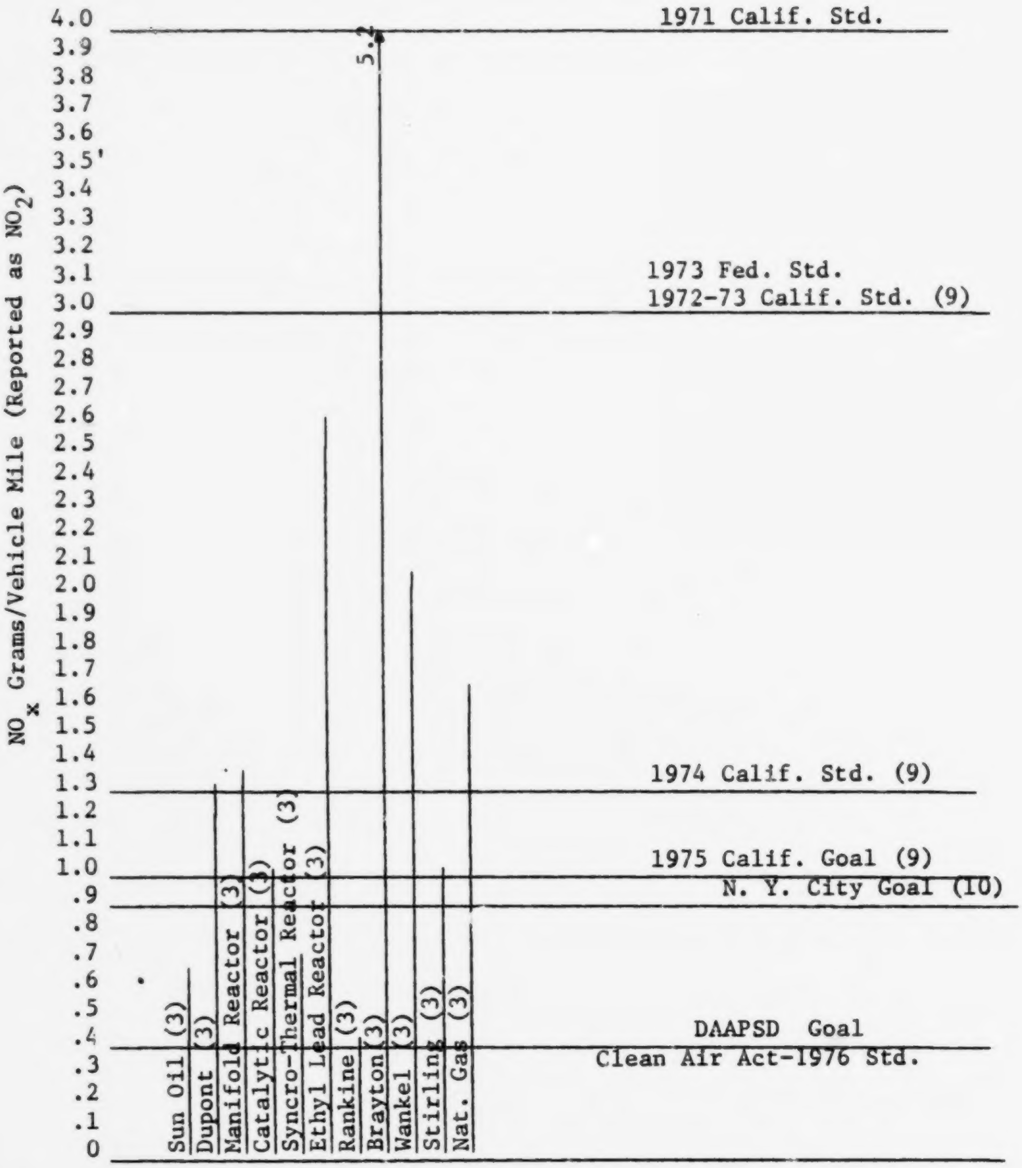

FIGURE 3

AUTOMOTIVE NO$_x$ EMISSIONS AND STANDARDS

For purposes of evaluating advanced automotive propulsion system emissions, a range of .35 grams/vehicle mile to 0.5 grams/vehicle mile has been established. This range encompasses all known goals and standards to be met after 1975. (Curve 1.3)

2.1.4 Sulfur Oxides

The conventional internal combustion automotive power plant emits small amounts of sulfur oxides from the exhaust; however, no standards have been set for control of this automotive emission. Generally the amount of sulfur in gasoline is quite low and as a result the automobile emits about 0.3 grams/vehicle mile of SO_x. This accounts for less than 4% of the total sulfur oxides input to the atmosphere.

While SO_x emissions from existing IC engines are low, the relative toxicity of SO_2 compared to CO (100 to 200 times greater) strongly indicates that the AAPS program must consider this pollutant in the evaluation of future power systems to insure that SO_x emissions resulting from the use of automobiles remain at acceptable levels. The largest known potential problem with SO_x emissions exists in the case of extensive use of an electric car. The SO_x emissions would come not from the automobile itself, but from the fossil fueled electric generating station which supplies the energy needs of the car. According to reference (18) a full size vehicle with air conditioning and power conveniences would use 0.5 Kw Hr/mile of electric power Generation of this power would require 0.95 lb of 12,000 BTU/lb coal. If the sulfur content for fossil fuel burned in electric generating plants is restricted to 0.6 lb sulfur per million BTU, the above vehicle would cause the emission of 6.2 grams of SO_2 per vehicle mile.

For the purpose of this study only primary SO_2 emissions will be evaluated to prevent serious complications which would arise if secondary pollution from oil refineries, etc., were included for other fuels. However, in the final selection process such potential secondary pollution problems should be studied in light of new technology for reducing electric generating plant emissions.

The upper limit for direct SO_x emissions (measured as SO_2) for this study is set at 0.5 grams per vehicle mile. The lower limit is set at zero. (Curve 1.4)

2.1.5 Particulate Matter

Particulate matter emitted from automobiles is for the most part submicroscopic liquid and solid particles. It is thought that these particles serve as condensation nuclei which may absorb pollutants. These submicroscopic particles thus act as carriers for other pollutants. Since they are extremely small and are airborne, these particles can be ingested into the respiratory tract without being intercepted by the nose or throat. It has been pointed out that a high concentration of potentially active nuclei from auto exhaust may be a significant factor in the formation of ice crystals. Such nuclei consist, apparently, of very small lead residues which react with atmospheric iodine to form lead iodide.

Lead particulates result from the burning of gasoline with lead additives. About 70% of the lead used in gasoline is emitted from the tail pipe: 30% settles almost immediately to the ground; 40% becomes airborne and can be ingested by humans.

Particulate emissions including lead for the uncontrolled automobile are approximately 0.3 grams/vehicle mile. As of now, no standards have been set for these particulates.

For the purpose of this study a range of 0.01 to .075 gram/vehicle mile was chosen for particulates. This includes the goal of 0.03 grams/vehicle mile established as a goal by DAAPSD. (Curve 1.5)

2.1.6 Smoke

Emission of visible smoke from properly maintained internal combustion engines is essentially non-existent. However, other engines such as the diesel and gas turbine do emit visible smoke. This smoke is in general a nuisance and is not particularly harmful.

Tests have been conducted on diesel engines to determine the opacity of smoke emissions. Using a U. S. Public Health Service full-flow light extinction smokemeter, the percent light obscured ranged from approximately 20% to 35% at maximum power. Federal standards have set the following opacity maximums for diesels:

1) 40 percent during the engine acceleration mode;
2) 20 percent during engine lugging mode.

The Advanced Automotive Power System program vehicle design goals do not establish a level of opacity for the new power system. However, it is felt that visible smoke should be held near zero opacity. Therefore, a range between 1% and 4.5% opacity was chosen, assuming the Public Health Service smokemeter as a standard measurement instrument. (Curve 1.6)

2.1.7 Odor

The odor nuisance is minimum from a well maintained gasoline IC engine. However, other engines do emit odors which may be objectionable to the general public. For example, diesels and aircraft turbine engines do emit odors which are a nuisance.

The measure of odor is based primarily on judgment. The Public Health Service has developed an odor quality/intensity kit which can be used as a "baseline" for the measure of odor.

The Advanced Automotive Power System program vehicle design goals do not provide a goal for odor. Nevertheless, new automotive propulsion systems must not emit an objectionable odor, and, therefore, odor emission must be considered in the evaluation of propulsion systems. Three points on a judgment measurement scale for odor can be established: undetectable; detectable; objectionable. Judgmental ranges around these points can be established based on the percentage of a test panel of people objecting to a given odor as follows: (Curve 1.7)

JUDGMENT SCALE	DETECTING ODOR	OBJECTING TO ODOR
Undetectable	0-20%	0
Detectable	20-80%	0
Objectionable	80-100%	Greater than 20%

2.1.8 Noise

Traffic noise has become of increasing concern in recent years and ways are being sought to reduce it. Vehicles make more noise at some times than at others depending upon their mode of operation and condition of maintenance. Measurements taken at roadside, 15 feet from a car going by at 60 mph, indicate that the nosie level ranged from 66 to 72 dBA. At full throttle the nosie level was 75 to 91 dBA.(12) Other studies(13) showed that passenger cars traveling at between 30 and 40 mph produced levels on the order of 65 dBA with a range between 59 and 71 dBA when measured at 50 feet.

Basically there are two types of noise generated by an automobile: tire, and engine and exhaust noise. The amount contributed by each to the total noise generated is not known.

SAE standard J986a "Sound Level of Passenger Cars and Light Trucks" has established a maximum sound level of 86 dBA measured at 50 feet and full throttle. DAAPSD has established a maximum level of 77 dBA in the vehicle design goals. In addition, DAAPSD has established a maximum low speed level (30 mph) of 63 dBA and an idle level of 62 dBA.

For the purposes of this study three ranges have been established. These are as follows:

Maximum external noise level (Curve 1.8) - 71 dBA - 83 dBA
Maximum external low speed noise level (Curve 1.9) - 57 dBA - 69 dBA
Maximum external idle noise level (Curve 1.10) - 56 dBA - 68 dBA

The range represents ±6 dBA around the values established by DAAPSD.

Although the noise levels to which the occupants of a vehicle are subjected are generally not high enough and exposure times not long enough to have a detrimental effect on hearing, noise does interfere with speech, increases fatigue and contributes to annoyance. The latter two effects can degrade the ability of the driver to safely operate the vehicle.

The noise inside an automobile is produced by the complex vibration of all body surfaces enclosing the car's interior and depends on (a) the characteristics of the applied forces such as the power system, wind, road vibration, tire noise, etc. and (b) the structural and acoustical characteristics of the vehicle.

A noise level which might produce hearing damage would be well above the level acceptable to the average motorist. Therefore, in establishing a maximum value for internal noise, it was assumed that minimum acceptability would be the ability for the driver to conduct a conversation in a normal communicating voice with a passenger. Therefore, the maximum ambient internal noise was set at 65 dBA up to maximum cruise speed. An arbitrary minimum was established at 50 dBA (Curve 1.11).

2.2 Operating Performance

2.2.1 Starting

To the average motorist, engine starting is probably the single most important operating characteristic of an automobile. The driver wants the engine to start everytime and wants it to start quickly under all environmental conditions.

In order to evaluate the starting characteristics of the engines the following are considered:

a) normal starting time,

b) cold soak starting time,

c) starting reliability.

The starting and restarting procedures will be in accordance with those outlined in the November 10, 1970 Federal Register paragraph 85.60 "Engine Starting and Restarting."

The Advanced Automotive Power System program "Vehicle Design Goals - Six Passenger Automobiles" states the maximum time from key on to 65 percent full power to be 45 seconds. The ambient conditions are 14.7 psia pressure, 60°F temperature. Allowing approximately 33% deviation to this maximum, the maximum on the measurement scales is established at 60 seconds. The minimum is 0 seconds which represents instantaneous starting. It is felt, however, that an engine capable of starting in an average time of less than 10 seconds would be satisfactory to the motoring public. (Curve 2.1)

Starting engines in low ambient temperature is of particular importance to motorists living in the colder climates. The vehicle design goals state that low ambient starting characteristics should be equivalent or better than the typical automobile spark-ignition engines. Therefore, the advanced power system must attain self-sustaining idle operation without further driver input within 25 seconds after a 24 hour soak at -20°F. The automobile must be available for normal road operation within 60 seconds after key-on. The maximum and minimum times for cold soak starting is 40 seconds and 5 seconds respectively (Curve 2.2).

Reliability of starting under all environmental conditions is of extreme importance. While no design goals have been specified for reliability, it is felt that any properly maintained engine which does not start 99% of the time would not meet the motoring public's criteria of acceptability. A failure to start condition occurs when there is any malfunction requiring an action other than that associated with normal manufacturers recommended starting operations. A range of 1% to 8% failure rate has been established for this parameter (Curve 2.3).

2.2.2 Idle Operation

The advanced automotive power system must be capable of operating under idle conditions both with and without a load on the engine. The power system must be capable of idle operations within all environmental condition ranges (see Section 2.4).

Idle operation is defined in the "Vehicle Design Goals" as follows:

> The fuel consumption rate at idle operating condition will not exceed 14 percent of the fuel consumption rate at the maximum design power condition. Recharging of energy storage systems is exempted from this requirement. Air conditioning is off, the power steering pump and power brake actuating device, if directly engine driven, are being driven but are unloaded. The torque at transmission output during idle operation (idle creep torque) shall not exceed 40 foot pounds

at the output shaft, assuming conventional rear axle ratios and tire sizes. This idle creep torque should result in level road operation in high gear which does not exceed 18 mph.

In addition to the above requirements, it is felt that the power system should be capable of idle for a minimum of 30 minutes without exceeding other operating limits such as temperature. The idle should also be adjustable to allow air conditioning operation while the vehicle is stopped.

The measure of idle operating capability will be a combination of factors which when totaled will provide a measure of the idling operations. The factors and ranges are as follows:

Fuel consumption (Curve 2.4)   5% - 18%

Torque at Transmission output (Curve 2.5)   0 - 50 ft. lbs.

Sustained Idle (Curve 2.6)   30 min. - 60 min.

2.2.3 Acceleration

Vehicle acceleration capability must be closely matched with conditions encountered in urban and open road driving. An underpowered automobile which cannot accelerate in the manner characteristic of most traffic can be a considerable safety hazard. Similarly, an overpowered automobile in the hands of an irresponsible driver may present a hazard. Therefore, vehicle acceleration capabilities must be scaled to meeting safety and traffic conditions.

Three acceleration characteristics are included in the "design goals." These are:

a) Acceleration from a standing start

minimum distance 0-440 feet in 10 seconds,

b) Acceleration in merging traffic,

25 mph to 70 mph maximum time 15.0 seconds,

c) DOT high speed pass maneuver

Maximum acceptable 15 seconds and 1400 feet.

The maximum acceleration values for evaluation purposes are within 20% of the "vehicle design goals." The minimum acceleration values are based on conversations with insurance companies and the criteria they use to define "Muscle Cars." The following represent the established ranges.

a) Acceleration from a standing start (Curve 2.7)

Distance in 10 seconds-min. 250 ft.
max. 800 ft.

b) Acceleration in merging traffic (Curve 2.8)

25 mph to 70 mph min. 6.5 sec.
max. 22 sec.

c) DOT high speed pass maneuver (Curve 2.9)

Max. 18 sec. 1800 ft.
Min. 12 sec. 1000 ft.

2.2.4 Velocity

The velocity the vehicle can attain is dependent on the aerodynamic drag, rolling resistance of the tires and engine power. The vehicle must be designed to attain and maintain speeds consistent with that of normal high speed traffic. However, safety dictates that maximum speeds be held at some reasonable level.

Three velocity levels have been chosen as an overall measure of this parameter. These levels are: cruise speed; maximum speed; grade speed.

a) Cruise speed - The "design goals" establishes the minimum cruise velocity on a level road to be not less than 85 mph. This assumes an accessory load of 4 horsepower. A deviation of ±5% is allowed when the power system is operated in the temperature range $-20^{\circ}F$ to $105^{\circ}F$. For the purpose of this study a minimum cruise speed of 65 mph and a maximum of 95 mph have been established. Maximum value will be assigned to vehicles which achieve a cruise speed between 80 and 90 mph (Curve 2.10).

b) Maximum speed - Maximum speed is defined as the top speed the vehicle can reach and maintain for short duration such as that required in passing. The "design goals" do not establish a maximum speed; however, for the purpose of this study a maximum speed range of 80 to 110 mph is designated. Maximum value will be assigned a vehicle with a maximum speed from 85 to 95 mph (Curve 2.11).

c) Grade speed - The ability of a vehicle to maintain speed going up a grade is important to the motorist driving modern highways. The "design goals" define three minimums for grade velocities:

(1) Minimum continuous cruise on a 5% grade shall be not less than 60 mph.

(2) The vehicle must be capable of achieving a velocity of 65 mph on a 5% grade, maintaining this velocity for 180 seconds when preceeded and followed by continuous operation at 60 mph on the same 5% grade.

(3) The vehicle must be capable of achieving a velocity of 70 mph on a 5% grade, maintaining this velocity for 100 seconds when preceeded and followed by continuous operation at 60 mph on the same 5% grade.

For the purpose of this study the third design goal was chosen as the measure of the vehicles grade velocity capability. The scale of measurement is a percent deviation scale from the specified minimum. The percent deviation includes both time and velocity. The range chosen is between 0% and 10% of stated minimums (Curve 2.12).

2.2.5 Range

Vehicle range is important to the motorist not only on long trips but in day-to-day commuting. With the growth of suburbs, commuters are generally faced with longer trips to jobs, shopping and entertainment. The requirement for frequent refueling is inconvenient to the motorist and would most likely be unacceptable.

The "vehicle design goals" has established a minimum range of 200 miles when measured in two modes of operation, city-suburban mode and cruise mode. The city-suburban mode is measured on the driving cycle which appears in the November 10, 1970 Federal Register, while the cruise mode range is measured at a constant 70 miles per hour.

For the purpose of this study, a no reserve range of 160 miles to 240 miles has been established. Two curves are presented for this parameter based on urban driving and cruise driving. (Curve 2.13 and 2.14)

2.3 Acceptability

2.3.1 Ease of Operation

The American motoring public has almost 70 years of experience behind them in driving vehicles powered by the conventional IC engine. They have become accustomed to its operations, performance, and instrumentation. Any radical change in the actions which the motorist must take to operate the engine will likely delay the acceptance of an advanced automotive power system.

The evaluation of ease of use would necessarily be judgmental, at least in the early development stages of an advanced engine. Later, after the engine has been integrated into a total automotive system, quantitative human factors measurements might be taken.

The scale for the evaluation will be from 0 to 1, with .5 representing the ease of operation of the conventional internal combustion engine as installed in 1971 six-passenger automobiles (Curve 3.1).

2.3.2 Starting

Starting operations should be no more complex than the starting operation for the conventional spark-ignition engine. No starting aids external to the normal vehicle system should be required for $-20^{\circ}F$ starts or higher temperatures. Complexity of the starting operation is a judgmental factor which can be qualitatively measured on a scale ranging from one to zero where one represents the conventional spark-ignition starting operation and zero represents the need for starting aids external to the vehicle systems (Curve 3.2).

2.3.3 Driver Comfort

Over the decades the American motoring public and the auto manufacturers have jointly "decreed" that driver and passenger comfort will play an important role in the design and construction of automobiles. Occupant comfort does have some real physical basis, for studies have shown relationships between comfort and driver and occupant fatigue.

Discomfort due to the many vibrations and motions found in an auto can result from many causes. In this evaluation we are concerned only with those caused by the propulsion system. The goal for this evaluation is that the propulsion system should not cause objectionable vibrations or motions which are transmitted to the driver or occupants of the vehicle. The parameter will be judgmental based on the percentage of a group of people who object to a given amount of discomfort (Curve 3.3).

2.3.4 Versatility

The conventional internal combustion engine is extremely versatile. It can range in horsepower from less than 1 hp to several thousand hp.

It has been used effectively with all types of automobile chassis and body styles, thus enabling the automobile industry to meet the transportation requirements and esthetic needs of the motoring public. An advanced automobile power system should be versatile enough to be usable in various sizes and styles of automobiles.

In evaluating an advanced power system, its versatility must be considered. Two major factors will be considered: adaptability to a range of vehicle sizes and adaptability to body styles. The adaptability of the advanced power system to body style will be on a scale from 0 to 1 with 1 representing no constraint on body style due to the power system. The value 0 represents severely constrained body styling. The conventional automobile engine would rate 0.5 on the scale. The adaptability of the power system will be evaluated for vehicle sizes ranging from urban car size (1600 pounds minimum curb weight) to luxury car size (approximately 5000 pounds curb weight). (Curves 3.4, 3.5, and 3.6)

2.4 Operating Environment

2.4.1 Ambient Operating Temperature

The vehicle propulsion system must be capable of starting and operating under the range of ambient air temperatures found in continental U. S. It is understood that some modifications may be required for starting or operating in extreme cold conditions. (For example, IC engines which are water cooled require anti-freeze and oil heaters are used in some areas during the coldest parts of winter). It is assumed that an acceptable vehicle propulsion system will not need adjustments or can be modified to operate at extremely cold temperatures with no greater difficulty than the present IC engine. Landsberg(14) gives some extreme ambient temperatures in the continental U. S. as follows:

Riverside, Yellowstone, Wyo.	Feb 9, 1933	-66°F
Greenland Ranch, Death Valley, Calif.	July 10, 1913	134°F

However, systems should not be penalized if they cannot achieve the rare extremes given above. The value judgments should be based on normally expected maxima and minima. Two value judgment curves will be generated for ambient temperature (viz. maximum, minimum).

DAAPSD has established design goals for ambient temperature as follows:

Maximum	125°F
Minimum	-40°F

The performance scale will be in degrees fahrenheit. The following data points are given initially.

Maximum Temperature	(Curve 4.1)	115°F - 130°F
Minimum Temperature Data	(Curve 4.2)	-20°F - -40°F

All candidate systems are expected to operate between -20°F and 115°F.

2.4.2 Altitude

The vehicle propulsion system must be capable of starting and operating at all altitudes normally encountered on U. S. roads. (Exceptions shall be allowed for trails or roads up the highest mountains.) The system must not degrade below acceptable levels during high or low altitude performance.

The following altitude ranges have been established based on altitudes normally encountered on U. S. highways.

Maximum altitude goal	11,000 ft MSL
Minimum altitude goal	-250 ft MSL

For high altitude operation the scale shall be in terms of reduced operating power at 11,000 feet expressed as a percentage of normal system operation at sea level. For below sea level operation no significant degradation will be allowed from normal system operation at sea level. The following data points are given (Curve 4.3).

11,000 Feet

System Operation degrades more than 35% of sea level design goals	- 0.0
System operates at 100% sea level design goal	- 1.0

2.4.3 Weather

The vehicle propulsion system must be capable of starting and operating during all types of rain, snow, sleet, hail, etc. This requirement does not apply to submersion of the propulsion system due to surface flooding. Any system which cannot be started or operated under these conditions must be capable of being shielded or otherwise adjusted to meet the requirement.

The scale shall be in terms of reduced operating power when any of these weather conditions occur. The following data points are given (Curve 4.4):

Weather Data Value		
The system can operate at 100% of design goals during rain, snow, ice, etc.	-	1.0
The system degrades greater than 15% during rain, snow, ice, etc.	-	0.0

2.4.4 Wind Speed

The vehicle propulsion system must be capable of starting and operating over the range of wind speeds (regardless of wind direction) normally encountered in the continental U. S. This parameter concerns propulsion system operation only, not total vehicle handling characteristics. All acceptable systems must be capable of operating during gale force winds (range 32 mph to 63 mph) without serious degradation. It is not required that an acceptable system be capable of operating during hurricane force winds (i.e., 75 mph or greater). Emergency vehicles required to operate during such conditions may be granted variance from the laws if acceptable candidate low-emission engines are not developed to operate at these wind speeds.

Propulsion system power in terms of % reduction due to wind speed should be evaluated at two wind speeds, 40 mph and 75 mph.

Data Points	Value at 40 mph (Curve 4.5)	Value at 75 mph (Curve 4.6)
Propulsion system not degraded due to wind	1.0	1.0
Propulsion system performance degrades 20% due to wind	0.0	0.8
Propulsion system performance degrades 50% due to wind	0.0	0.0

2.4.5 Dust

The vehicle propulsion system must be capable of starting and operating under roadway dustloads (except as explained below for sandstorms) normally encountered by current automobiles. No part of the propulsion system shall be so sensitive to dust as to require maintenance which is more frequent or complicated than that of the IC engine.

The vehicle propulsion system shall not be required to start or operate in a severe sandstorm or severe duststorm. A sandstorm is defined as a strong wind carrying sand through the air, the diameter of most particles ranging from 0.08 to 1 mm.(15) In contrast a duststorm is composed of smaller particles whose mean diameter is considerably less than 0.08 mm. According to the National Weather Service, if visibility is reduced to between 5/8 and 5/16 statue mile, a sand or duststorm is reported; if visibility is reduced to less than 5/16 statue mile, the storm is classified as "severe".

Sandstorms and duststorms are common in certain parts of the U. S. for example, reference 15 cites the "Santa Ana" duststorm which often occurs in the winter in the desert areas of southern California. It would be desirable to have the vehicle propulsion system operate during non-severe sand or duststorms, but candidates which fail this test should not be severely penalized.

The scale for dust measurement should be in terms of visibility. The reduction of propulsion system efficiency below some critical level should constitute failure at the selected visibility level. The following data points are given (Curve 4.7):

Data	Proposed Value
If the system operates for at least 30 minutes when the visibility due to dust or sand is 5/16 mile or less	1.0
If the system operates for at least 30 minutes when the visibility due to dust or sand is 5/8 mile	0.8
If the system does not operate when the visibility due to dust or sand is 1 mile or greater	0.0

2.5 Safety

Safety is of paramount importance in the starting and operating of the vehicle propulsion system. The same importance is also placed on the energy supply subsystem of the vehicle propulsion system. In addition, safety considerations should also be considered in the original production and subsequent maintenance of the propulsion system and the energy supply subsystem. The internal combustion engine itself has a phenomenal record of safety in terms of personal injury and property damage. The present type of fuel storage system has also proven to be quite reliable in normal operations, but has presented some safety problems in vehicle accidents. It is imperative that safety always be a prime consideration. A secondary safety consideration which is also of considerable importance is the safety associated with the production, servicing and maintenance of the vehicle propulsion system.

Although DAAPSD has not established any specific safety goals they have emphatically stated that safety is always of paramount importance in motor vehicle R&D. Reference 16 discusses this point, briefly.

Value functions for eight parameters will be developed in the safety category. These will be broken down into six functions pertaining to vehicle operation and two functions pertaining to production and maintenance. The operating functions will be further divided into groups involving normal vehicle operation and vehicles involved in highway accidents. The functions proposed are as follows:

1. Propulsion system safety during normal operation and accidents. (Curve 5.1).
2. Energy supply safety during normal operation (Curve 5.2).
3. Energy supply safety during high speed accidents (Curve 5.3).
4. Energy supply safety during low speed accidents (Curve 5.4).
5. Safety during propulsion system production (Curve 5.5).
6. Safety during propulsion system servicing and maintenance (Curve 5.6).

Since the current IC engine customarily can be operated up to as much as 100,000 miles without complete failure it is proposed that the first four parameters listed above be structured on a nominal scale relating to hazardous failure of the propulsion or energy supply system. A hazardous failure is defined as one which causes either significant injury to personnel or significant property damage to the vehicle itself and/or to surrounding property. The scale for the functions relating to production and maintenance should also be nominal based on a relative comparison with the current IC engine.

Another safety factor which will be considered is the use of hazardous materials in the power system. Materials used must be no more hazardous than those used in the IC engine. If hazardous materials are required, protective measures must be taken to prevent exposure to personnel operating or maintaining the vehicle under normal and emergency (accident) conditions.

Finally, the power system will be given nominal credit if it possesses devices which allow it to fail-safe. Fail-safe applies to the prevention of power system damage and/or personnel injury.

2.6 Personnel and Facilities

The availability of a vehicle using an advanced low emission propulsion system to the motoring public depends on a number of factors. Basically it depends on the automobile industry's ability to modify existing facilities or build new production facilities, and re-train production, maintenance and service personnel.

2.6.1 Time to Consumer Availability

It is estimated that it takes 3 to 5 years to place a technologically feasible emission control technique involving significant IC engine modification into universal mass production. Further, it has been estimated that it will take about 7 to 10 years to develop, test, and tool up for mass production of vehicles using electric power systems.

In evaluating advanced power systems, the time to consumer availability is very important. The following goal expressed by the President places the availability into context "...with the goal of producing an unconventionally powered, virtually pollution free automobile within five years." (1975)[*]

By meeting this goal and allowing 3 additional years to establish a production capability of approximately 2.5 million automobiles, 1978 appears to be a reasonable goal for consumer availability. Therefore, a range from 1975 to 1980 has been established for the time to consumer availability. However, any extremely promising advanced technique will be given some credit no matter how far in the future it may become available. (Curve 6.1)

2.6.2 Facilities

The establishment of production, service and maintenance facilities for advanced power systems and associated energy supplies will have an impact on the time to consumer availability and cost to the consumer. If the facility requirements for advanced engines closely match those of the present automobile industry, a distinct advantage occurs in terms of cost and time to consumer availability. The evaluation of candidate advanced power systems will consider the following factors as related to facilities.

a. Lead time required for changeover of production facilities. The scale used will be months to accomplish. (Curve 6.2)

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[*] President Nixon's Message on Environment, February 10, 1970.

Range of values: 24 - 72 months

b. Complexity of production facilities changeover including residual value of present facilities. Scale to be used will be nominal. (Curve 6.3)

c. Lead time required for changeover of field service and maintenance facilities. Scale to be in months to accomplish. (Curve 6.4)

Range of values: 6 - 48 months

d. Complexity of field facilities changeover including residual value of present facilities and availability of new energy stations. Scale to be used will be nominal. (Curves 6.5 and 6.10)

2.6.3 Personnel

Personnel training requirements for producing, servicing and maintaining advanced low-emission power systems may prove to be a major problem in the transition from the conventionally powered automobile. Retraining a work force of over 1 million mechanics (17) will be a time consuming costly undertaking. However, time and cost will depend on the engine complexity, changes necessary in other automobile components such as transmissions and electrical system, and the ability to use electronic diagnostic techniques to identify engine malfunctions.

Another critical personnel factor is the impact of an advanced power system on the size, skill levels, and location of the automotive labor force. Significant changes in the size, distribution of skills, and/or location of the labor force must be carefully assessed as to economic impact and acceptability.

Evaluation of the effect of candidate power system on personnel will include the following:

a. Lead time required for production personnel training - Scale will be in weeks to accomplish; (Curve 6.6)

   Range of values: 0 weeks (i.e., no additional training required)
   - 60 weeks

b. Educational levels required for production personnel - Scale will be in terms of years of school or equivalent technical training required; (Curve 6.7)

   Range of values: 8 years (grade school) - 12 years (high school)

c. Lead time for service and maintenance personnel training - Scale will be in months to accomplish; (Curve 6.8)

   Range of values: 0 months (i.e., no additional training required)
   - 24 months

d. Educational levels required for service and maintenance personnel - Scale will be in terms of years of school or equivalent technical training required; (Curve 6.9)

Range of values: 8 years (grade school) - 12 years (high school)

Absolute maximum - 14 years

2.7 Propulsion System Technical Parameters

A vehicle propulsion system is made up of the following components:

- energy storage devices;
- energy converters;
- power conditioners.

Energy storage devices serve the function of storing energy in various forms for controlled release to other elements in the propulsion system. Stored energy may take a variety of forms, including:

- chemical energy, as through the oxidation (combustion) of fossil fuels or electro-chemical conversion in primary (fuel) cells;
- electrical energy, as in secondary cells (storage batteries);
- mechanical energy, as in rotating flywheels.

Energy converters are those components which alter the form of energy as, for example, in converting stored chemical or electrical energy into the mechanical energy needed to propel a vehicle. Thus, common examples of energy converters would include:

- heat engines (chemical-to-mechanical energy conversion) such as gas turbines, Rankine cycle (steam) engines, spark-ignition engines, and diesel engines;

- electric motors (electrical-to-mechanical energy conversion).

Power conditioners are those elements which transform energy flow (power) without changing its basic form. In this component category the most common examples would include:

- transmissions (e.g., mechanical, hydrokinetic, hydrostatic and electrical) which accept shaft power at one torque and speed and deliver the same power, minus internal losses, at a conditioned torque and shaft speed);
- solid state controls, which regulate and condition electric power supplied by an electrical energy source (e.g., battery) to an electric motor.

In evaluating advanced automotive propulsion systems, it is essential that, in addition to the entire propulsion system, the inidvidual components (energy storage devices, energy converters, and power conditioners) should be evaluated as well. There are several reasons for evaluating individual components:

- credit should be given to a system having some exceptional components, even though the complete system may have unsatisfactory characteristics;
- incorporating component evaluation into the Structured Value Analysis (SVA) will permit this evaluation tool to be used for rating alternate propulsion system components;
- individual component evaluation will greatly aid analysis why one propulsion system performs differently from another.

Thus, under the broad category of propulsion system characteristics, the chosen technical parameters are listed under the four subcategories of:

- energy storage characteristics;
- energy converter characteristics;
- power conditioner characteristics;
- overall propulsion system characteristics.

2.7.1 Energy Storage Characteristics[*]

2.7.1.1 Specific Volume. This parameter is the actual total volume of the energy storage system, divided by its total energy content. This parameter includes both consumable (e.g., combustible fuel) and non-consumable (e.g., fuel tanks, batteries, flywheel assembiles) elements. The appropriate range and units for this parameter are:

$$.003\ \text{ft}^3/\text{hp hr.} \; - \; .8\ \text{ft}^3/\text{hp hr.}$$

The minimum (.003) is equivalent to gasoline fuel and the maximum (.8) is appropriate to typical flywheel assemblies. (Curve 7.1)

2.7.1.2 Specific Weight. The same comments apply here as for 2.7.1.1. The range and units are:

$$.15\ \text{lbm/hp hr.} \; - \; 100\ \text{lbm/hp hr.}$$

Gasoline fuel and flywheel assemblies are the appropriate examples for the respective values. (Curve 7.2)

2.7.1.3 Specific Costs (Consumable Elements). Unlike volume and weight, energy system cost must be broken into consumable and non-consumable elements, the former representing refueling, the latter representing capital costs for the energy storage system. The range and units for refueling costs are:

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[*] For 200 mile range, mode 2 driving cycle (see AAPS Design Goals).

.008 \$/hp hr. - .04 \$/hp hr.

The cost range, including estimated taxes, is based on current costs for gasoline, for the minimum, and five times that cost for the maximum. It should be noted that gasoline is the least expensive, per unit of energy content, of fuels in common use today; electricity, if it were assigned the same level of road taxes as gasoline, would be about twice as costly as gasoline. (Curve 7.3)

2.7.1.4 Specific Costs (Non-Consumable Elements). The capital cost for energy storage has the same units as refueling costs and should cover the following range:

.025 \$/hp hr. - 200 \$/hp hr.

where the range limits correspond approximately to a conventional automobile gasoline tank on one hand and a flywheel assembly on the other. The very wide range of values necessary for this parameter is indicative of the very low cost of fossil fuel storage tanks compared to the cost of other systems, such as electrical and mechanical energy storage devices. The commonly used lead-acid battery, for example, has a specific capital cost of 40 \$/hp hr. (Curve 7.4)

2.7.1.5 Known Fuel Reserves. It is necessary to consider this parameter because the real cost of a particular fuel, in terms of such factors as effect of fuel usage on the environment, is not adequately reflected by the actual retail cost of fuel. The selected range and units are:

100 yrs @ current consumption rate

10 years @ current consumption rate

It is felt that any system requiring a fuel for which known reserves are less than ten (10) years on a world wide basis should be given little credit in this category. The fuel recovery industry standard requires approximately 20 years lifetime of reserves for economic operations. Known reserves is selected as the appropriate parameter in preference to estimated, but untapped reserves. (Curve 7.5)

2.7.1.6 Ease of Refueling. A nominal scale (EGFP) of values is chosen for this parameter. This parameter takes account of the actual refueling process once the vehicle has arrived at an energy station. Such factors as refueling time, number of personnel required, safety hazards, and special facilities are included. The value assigned to refueling ease within this nominal scale will be guided by the following examples: (Curve 7.6)

E - Liquid Fuel, having volatility equal to or less than that of gasoline;

G - Gaseous Fuels including those which are stored as compressed gases or liquids under pressure, such as propane and butane;

F - Rapid Battery Charge or Replacement; also cryogenically - stored fuels such as liquid natural gas;

P - Lead-Acid Batteries requiring slow (over-night) charge.

2.7.2 Energy Converter Characteristics

2.7.2.1 Specific Volume[*]. The general comments related to specific volume, weight, and cost already stated for the energy storage system also apply here. For specific volume the range and units selected are:

$$.03\ ft^3/hp \ - \ .2\ ft^3/hp$$

The range limits correspond roughly to an electric motor on the low volume end of the scale and a Stirling engine at the high end. (Curve 7.7)

2.7.2.2 Specific Weight [*]. Selected range and units are:

$$.5\ lbm/hp \ - \ 10\ lbm/hp$$

where, as for specific volume, the range limits correspond approximately to electric motors (in particular, high speed induction motors) at low specific weight and Sitrling engines at the other end of the scale. (Curve 7.8)

2.7.2.3 Specific Cost[*]. The only cost here is the initial capital cost, and the appropriate range of this parameter is defined by:

$$2\ \$/hp \ - \ 15\ \$/hp$$

where, again, electric motors (in particular, squirrel cage induction motors) and Stirling engines are the corresponding equivalents; the Stirling engines being the more expensive.(Curve 7.9)

2.7.2.4 Power Range (Scalability)[*]. This parameter is deemed essential as a means of rating the applicability of a particular energy converter to other advanced propulsion system applications in different power ranges. For example, a heat engine suitable for large passenger automobiles and over-the-road trucks and buses, but not practical in the power range required of compact urban vehicles, is considered to be of less value than a heat engine which is practical for all three applications. It seems most appropriate to evaluate power range (scalability) by assigning separate value functions for the minimum practical design power and the maximum practical design power for a particular energy converter concept. For minimum design power, the appropriate range is judged to be: (Curve 7.10)

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[*] At maximum continuous hp output.

10 hp - 200 hp.

For maximum design power, the appropriate range was selected as: (Curve 7.11)

40 hp - 400 hp.

Although none of the above values correspond to particular examples, it is worth noting, by way of further illustration, that automotive gas turbines are impractical and expensive at very low power levels because of high internal losses, resulting in low efficiency, and small dimensions requiring high machining tolerances. On the other hand, Rankine cycle (i.e., "steam") engines become impractical at high power levels because of the relatively large size of the heat rejection components (condensor, fan, etc.).

2.7.2.5 Stall/Design Point Torque Ratio. This parameter and the one that follows influence the type of transmission or power conditioner that an energy convertor may require in order to adequately propel a vehicle. A high stall/design point torque ratio for a heat engine or electric motor makes practical a direct drive connection to the wheels. On the other hand, a low ratio will require a transmission or other power conditioning device to increase the low speed torque available at the wheels. The range of values chosen for this dimensionless ratio is:

0.5 - 5.0

An internal combustion engine which cannot be stalled would, in effect, have a zero stall/design point torque ratio. As additional examples, two-shaft gas turbines will frequently have torque ratios of two or more, while reciprocating Rankine engines and electric traction motors may have even higher stall/design point torque ratios. (Curve 7.12)

2.7.2.6 Minimum/Design Point RPM Ratio. This parameter is important for assessing the power conditioning requirements of an energy converter. For example, any energy converter, such as internal combustion engines, single-shaft turbines, and AC electric motors, which cannot be stalled without either damaging the system or requiring a restart procedure, will demand a clutch or some other slipping device, such as a hydraulic coupling, when the vehicle is stalled. The range assigned to this ratio is: (Curve 7.13)

0.0 - 1.0

2.7.2.7 Regenerative Power Efficiency. This parameter is the efficiency of the energy converter when operated in a regenerative mode. In a regenerative mode, the kinetic energy of a vehicle in motion is returned, less losses, through the propulsion system to the energy storage components. The efficiency will have the following range:

0.0 - .9

As an example, an IC engine is incapable of returning any of the vehicle kinetic energy to the energy storage system (in this case, stored fossil fuel) and would hence have a regenerative power efficiency of zero. Electric motors, on the other hand, are highly efficient in regenerative power modes. (Curve 7.14)

2.7.2.8 Absorption Power Effectiveness. In contrast to the previous parameter (regenerative power efficiency) this parameter measures the ability of a particular energy convertor to absorb power in a vehicle braking mode, regardless of whether the power is stored (regenerative braking) or dissipated (dynamic braking). The most appropriate definition for this parameter is the ratio of the maximum continuous braking power that can be absorbed at the output shaft to the maximum continuous output power of the energy converter. the appropriate range for this ratio parameter is defined by:

.1 - .9

Electric generators have high absorption power effectiveness (frequently greater than 1.0) while the IC engine has a value considerably lower. The minimum value of .1 for this parameter is chosen with reference to the value for an IC engine. (Curve 7.15)

2.7.2.9 Mechanical Efficiency at Maximum Continuous Horsepower. Although efficiency is generally a very strong function of operating mode (load, speed) and can be adequately defined only by a complete performance map of the device, it is nevertheless useful to evaluate an energy converter on the basis of a characteristic efficiency such as the efficiency when operated under maximum continuous load. This efficiency would adequately describe the engine when used in hybrid energy-storing propulsion systems which permit the energy converter (usually a heat engine) to operate continuously at maximum load. The parameter range is defined by:

.15 - .9

Electric motors correspond to the upper end of the range, while fossil fueled heat engines are typical of the low end of the efficiency range. It should be noted that the higher efficiency of the electric motors is partly compensated for by the higher electric energy costs which in essence reflect the inefficiency of the fossil fuel energy conversion process at the generating station. (Curve 7.16)

2.7.2.10 Response to Load Change. This parameter is defined by the time required for the energy convertor to change from zero or idle to maximum rpm under no load conditions. So defined, this parameter is thought to be an adequate measure of the energy converter's ability to respond to either load or speed changes. The selected range is:

1 second - 5 seconds

Typical of a system with rapid response is the IC engine which requires between one and two seconds to go from idle to maximum rpm. Systems having high thermal inertia or rotational inertia would require several seconds for this speed change. Five seconds is considered the maximum tolerable lag. (Curve 7.17)

2.7.2.11 Overload Capability. This parameter is essential for sizing an energy converter to a particular application or duty cycle. It is defined as the ratio of the difference between peak horsepower for five (5) minute operation and maximum continuous horsepower to the maximum continuous power of the device. The five minute overload is assumed to take place following a stabilized maximum power output operating mode. The range for overload capability ratio is given by:

$$0.0 - 3.0$$

where the larger value is typical of large induction motors and the lower value represents no overload capability whatsoever. (Curve 7.18)

2.7.2.12 Sensitivity to Fuel Quality. A nominal scale of high, medium, low (HML) is chosen for measuring fuel sensitivity. An energy converter having high sensitivity to fuel quality will tend to require more costly fuel, making refueling more inconvenient by decreasing the number of acceptable refueling stations, and decrease the system's reliability in the event an inappropriate fuel is accidently used. The scale is defined by the following examples: (Curve 7.19)

H - High compression Spark Ignition (SI) engine

M - Diesel

L - External combustion engines and gas turbines

2.7.3 Power Conditioner Characteristics

Unless noted otherwise, the description of the parameters and the appropriate units for power conditioners is the same as that given for the corresponding energy converter parameters.

2.7.3.1 Specific Volume.* The range for this parameter is set at:

.003 cu.ft/hp - .04 cu.ft/hp

The low end of the scale (.003) is typical of a standard automotive 3-speed box while the high end corresponds to a heavy duty hydrostatic transmission. (Curve 7.20)

2.7.3.2 Specific Weight.* The range for this parameter is given by:

0.4 lbm/hp - 3.0 lbm/hp

where the range limits correspond to the same examples cited under 2.7.3.1. (Curve 7.21)

2.7.3.3 Specific Cost.* The range here is defined by:

0.3 \$/hp - 3.0 \$/hp

where the low cost end of the scale represents the standard automotive

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*At maximum continuous power input.

3-speed transmission and the upper end is arbitrarily set at a factor of ten greater. (Curve 7.22)

2.7.3.4 Power Range (Scalability)[*] The range for minimum design power is defined by: (Curve 7.23)

10 hp - 200 hp

For maximum design power, the range is defined to be: (Curve 7.24)

40 hp - 400 hp

2.7.3.5 Reversing Power Effectiveness. This parameter is intimately related to the regenerative and absorption power parameters defined above for the energy converter. It measures the ability of the power conditioner to pass power in the reverse direction and is defined as the ratio of maximum continuous power in reverse power direction to maximum continuous power in forward power direction, measured at the location of power input in both cases. The range is defined by:

0.05 - 1.0

Note that this is not an efficiency; efficiency in reversing power modes is discussed below. Examples of power conditioners having high reversing power effectiveness are mechanical transmissions using conventional spur gears and electrical transmissions. Power conditioners which cannot easily handle reverse power flow include mechanical transmissions with high single step ratios, such as in worn gearing, and some hydraulic torque converters. (Curve 7.25)

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[*] At maximum continuous power input.

2.7.3.6 Mechanical Efficiency at Maximum Continuous Power. The range is defined by:

0.8 - 0.95

Mechanical transmissions are typical of the high efficiency end of the scale, while hydrostatic transmissions represent the low efficiency end. (Curve 7.26)

2.7.3.7 Mechanical Efficiency in Reverse Power Direction. This parameter complements item 2.7.3.5, reversing power effectiveness, in the sense that the former applies only if the latter has a finite value (that is, if reversing power effectiveness is greater than .05). In other words, if a power conditioner cannot accept reverse power flow, it makes no sense to talk about efficiency in reverse power flow; thus, an appropriate way to handle these two parameters might be to treat them as a product. The reverse power efficiency is measured at maximum continuous reverse power with range defined by:

0.50 - 0.95

Standard mechanical transmissions are typical of the high efficiency end of the range while hydrostatic transmissions and some electric power conditioners might be closer to the lower end of the scale. (Curve 7.27)

2.7.4 Overall Propulsion System Characteristics

The following parameters evaluate the entire propulsion system as a unit. These parameters will be given greater weight than the individual component parameters in the final system evaluation.

2.7.4.1 Average Propulsion Efficiency at the Wheel, Mode 1. Two modes of vehicle operation, an urban/suburban mode and a cruise mode are defined in the AAPS Design Goals. Mode 1 is the urban/suburban duty cycle. To properly account for the effect of load and speed on system efficiency, it is necessary to integrate the system performance over the prescribed duty cycle to determine an overall propulsion efficiency. This integration can be performed in a straight forward manner, numerically, once the performance characteristics of each component of the system are known. This parameter is therefore defined as the ratio of mechanical energy delivered to the wheel divided by the fuel energy consumed for the entire cycle. The range is defined by:

0.1 - 0.7

All-electric vehicles may have propulsion efficiencies as high as .7, whereas the conventional IC engine system may have an efficiency approaching .1. As noted earlier, high efficiency of the electrical system is partly offset by the higher energy cost. (Curve 7.28)

2.7.4.2 Average Propulsion Efficiency at the Wheel, Mode 2. In the cruise mode, the average propulsion efficiency will tend to be higher so that the appropriate range should be: (Curve 7.29)

0.15 - 0.8

2.7.4.3 Total Volume.* The total volume is assumed to be the package volume of all elements in the propulsion system. The range is defined by:

15 cu. ft - 40 cu. ft

The range is based on the AAPS Design Goal of 35 cubic feet. The low volume end of the range is equivalent to 1/3 of the design goal plus the volume occupied by 25 gallons of a fossil fuel. (Curve 7.30)

2.7.4.4 Total Weight.* The range is defined by:

800 lbm - 1600 lbm

The range is selected on the basis of the AAPS Design Goal of 1600 lbm. for the maximum allowable propulsion system weight. The lower weight limit was arbitrarily set at one half the design goal. (Curve 7.31)

2.7.4.5 Use of Scarce Materials.* This parameter is included for the same reasons as the fuel reserves parameter (2.7.1.5): the raw material cost may not accurately reflect the true cost to society of using a scarce material. Only the most critical material in the propulsion system is to be used for defining this parameter. The definition is:

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*For 200 mi. in Mode 1 or Mode 2, which ever gives the highest value.

$$\frac{\text{Total known reserves (tons)}}{\text{Amount required per million vehicles (tons)}}$$

This dimensionless parameter has the following range:

20 - 1000

The range values can be put into perspective by noting that, for the case of the lower value, recycling of the critical material must provide nearly 100% of the material required for new vehicles well before 20 million new vehicles using the scarce material have been built. The high end of the range was arbitrarily set at fifty times the lower limit, corresponding to a 100 year supply at a rate of 10 million vehicles per year. (Curve 7.32)

2.8 Reliability and Maintenance

2.8.1 Complexity of System

This parameter is defined simply as the number of loaded, moving parts in the propulsion system. In this category, ball bearings, for example, are counted as being one part for the entire bearing assembly. Peripheral components such as carburetor elements or electrical relays are not counted as loaded, moving parts. The range is defined to be:

6 loaded, moving parts -
150 loaded, moving parts

An electric drive system consisting of 2 direct connected electric motors (1 rotor and 2 bearings each) would have 6 loaded, moving parts. An IC engine (V-8) with a hydrokinetic (automatic) transmission would have close to 150 loaded, moving parts. (Curve 8.1)

2.8.2 Ease of Routine Service

By this parameter is meant the simplicity of routine maintenance, including such factors as frequency of service, man-hours per routine servicing, special equipment required, and the availability of servicing locations. A nominal scale of high, medium, and low (HML) is chosen here, with ratings assigned consistent with the following examples: (Curve 8.2)

H - Simple battery-powered electrical systems (e.g., periodic contactor and brush replacement)

M - Gas turbines (e.g., periodic oil change and infrequent scheduled overhauls)

L - IC engines (e.g., periodic oil change and engine tune-up and infrequent, unscheduled overhauls)

2.8.3 Expense of Unscheduled Repair

This item applies to a typical major failure of the propulsion system, where failure is defined in 2.8.6. As examples, we would include connecting rod bearing or valve failure of an IC engine, disc or rotor failure of a gas turbine, and a motor burnout in an electrical system. The chosen parameter is expense of repair of such typical failures as a fraction of the initial cost of the vehicle, with the range given by: (Curve 8.3)

2% of initial vehicle cost -

30% of initial vehicle cost

2.8.4 Design Life

Design life is the estimated mean operating life. Determination of this parameter for a particular system should be based on standard techniques currently in use in the manufacturing industry most closely related to the nature of the propulsion system. A range for design life is based on the AAPS Design Goal of 3500 hours. (Curve 8.4)

2900 hours - 4100 hours

2.8.5 Period Between Routine Servicing

This parameter is self-explained, and is related to the ease of routine servicing (2.8.2), and has the following assigned range:

1 month (or 1,000 miles) - 12 months (or 12,000 miles)

The smaller value (months or 1,000's of miles) will be used in all cases where both are given. (Curve 8.5)

2.8.6 Estimated Mean Miles Between Failures

This parameter is admittedly difficult to determine for novel systems with no history of endurance testing. Nevertheless, it should be estimated for all systems. The following defintion of failure should be used:

> 'failure means breakage or malfunction of a propulsion system component such that operation of the system is prevented or cannot continue without further damage to the system'

The following range is chosen: (Curve 8.6)

6,000 miles between failure - 50,000 miles between failure

SECTION III

COST AND ECONOMIC FACTORS

3.1 Introduction

The cost evaluation of the Advanced Automotive Power System (AAPS) program will be based on a comparative system cost approach. Under this approach system value/cost relationships will be established for each candidate. The results will then be used to rank the AAPS candidates on a system value versus system cost basis.

The cost evaluation will consider four major cost and economic categories: Research, Development, Test and Engineering; Cost to the Consumer; Economic Reallocation; Cost to Governments. Each candidate system will be evaluated in terms of the costs required to make it suitable for mass production and procurement by the motoring public. This cost will include the research, development, test and engineering efforts to be accomplished under the AAPS program. The remaining three cost and economic categories will be used to evaluate the candidate AAPS's ability to compete economically with the conventional internal combustion engine.

The following paragraphs discuss the four cost categories in more detail.

3.2 Research, Development, Test and Evaluation

The RDT&E cost represent those costs which must be expended in order to bring the AAPS to an operational level. The RDT&E costs will be incurred by DAAPSD and/or the firms developing the candidate system and can be summarized as follows:

a. R&D manpower for engine design and fabrication.

b. Materials for engine fabrication.

c. Test and evaluation equipment.

d. Fuel for test and evaluation.

e. Manpower for test and evaluation.

f. Administrative, overhead and profit costs.

The RDT&E costs incurred throughout the AAPS program include proof-of-principle demonstrations, design efforts, first and second generation hardware fabrication. These costs will be used in the evaluation of relative performance and effectiveness of a candidate low-emission propulsion system against the total cost of developing and testing the system.

The RDT&E costs associated with developing an automotive propulsion system which will meet emission standards, while providing the performance and reliability of existing propulsion systems at a reasonable cost to the consumer is expected to be very large. A recent EPA report stated that U. S. automakers are now spending more than $330 million a year in research and development on emission reduction. These funds are being spent to develop internal combustion engines suitable for mass production within the time limits set by the Clean Air Act. In the next four years, $73 million(7) will be spent for Government sponsored research to develop alternatives to the internal combustion engine. Another $20 million will be used for incentive programs under which the Government will purchase and test vehicle prototypes turned out by manufacturers.

The evaluation of AAPS candidates must consider the RDT&E costs involved. Since the candidates are in different stages of development the RDT&E costs versus the system value must also account for the technological risk and uncertainty associated with the development. A ranking of the candidates will then be made based on the value/RDT&E cost relationship as adjusted to consider the risk and uncertainties involved.

3.3 Cost to the Consumer

Consumer spending on automobiles represents a major factor in the nations economy as well as a major budget item for the 82% of the families in the U. S. who own automobiles. In 1970, consumers spent approximately $72.4 billion on the purchase and operation of automobiles. This represents approximately 12.0% of the total goods and services purchased by individuals in 1970.

The cost to the consumer is probably the most important measure of the economics of conversion. This cost reflects the vast majority of all the costs which will be associated with converting from the IC engine to an advanced power system since under the free-enterprise system a manufacturer attempts to recoup all costs plus a profit. Thus, the automobile industry would pass on to the consumer those costs associated with converting to the advanced engine.

The following factors are used to evaluate the cost to the consumer:

1. Consumer Purchase Cost
    a. Total cost of automobile.
    b. Total cost as a percentage of median family income.
    c. Cost of power system.
2. Consumer Operating Cost
    a. Fuel cost - $/mile
    b. Oil cost - $/mile
    c. Maintenance, repairs and replacement parts - $/mile
    d. Accessories - $/mile
    e. Insurance - $/mile
    f. Taxes, and fees - $/mile.

3.3.1 Automobile Purchase Price

The purchase price of an automobile is based on the cost of manufacturing, distributing and selling the vehicle. In estimating the cost of an automobile powered by an unconventional, low-emission power system, three major cost items should be considered: capital cost, material cost and labor cost.

In 1969, fixed capital expenditures by motor vehicle and parts manufacturers for new plants and equipment was estimated to be $1.65 billion(1). Much of this expenditure was for normal replacement of equipment and retooling for new automobile models. The capital expenditures which may be required to convert existing manufacturing facilities to the production of an unconvention engine will be dependent on two factors. First is the timing of conversion. If the timetable for conversion of production facilities from the IC engine to the AAPS can be matched with the normal replacement of plants and equipment, the capital cost impact would be minimized. The second major factor is the type of AAPS to be manufactured. If the equipment required to produce the IC engine can be modified to produce the AAPS, capital investment costs could be held to a relatively low level. However, if the AAPS involves an entirely new production technique and new production equipment such as that required for the Brayton Cycle engine, capital costs might be very substantial. Therefore, in order to estimate this cost, it will be necessary to study the major components of the candidate AAPS to determine the manufacturing procedures which must be followed and to identify major tooling changes necessary to produce the engine.

Capital investment needed for the distribution and sales of the automobile should be very low. Assuming the manufacturers elect a gradual conversion strategy, wholesale and retail dealers will most likely be able to make use of existing automobile showrooms and sales facilities, thus keeping capital expenditure to a minimum.

The cost of materials and the cost of semi-finished or finished parts could change significantly with the introduction of the AAPS. The material cost will depend on the availability of the basic material and the complexity of the forging, machining or other processing techniques required in finishing the material for use in the engine. For example, in August 1971, the price for carbon steel was \$.1125 per pound while aluminum was \$.29 per pound (20). It has been estimated that the cost of a finished high-ductility forged part would be \$7-\$8 per pound (21). In order to estimate the material cost of an AAPS candidate, the design must be carefully analyzed to determine the materials required and the finishing operations which must be performed.

There should be no significant change in the material cost associated with the distribution and sales of an automobile powered by an AAPS.

Labor cost represents a relatively small portion of the automobile cost. In 1967, the average labor cost/automobile was approximately \$260.00 which represented approximately 12% of the automobile shipment value (22). The conversion to a mass produced AAPS may present two production labor problems. First the conversion may bring with it a change in the number of direct manhours which must be spent in manufacturing the AAPS. The automobile industry currently employs machines and automated equipment suited for high volume assembly line operations, thus, direct labor costs are small when compared to the material and material processing costs. If, however, the production of the AAPS cannot be automated to the degree currently employed, higher labor costs can be expected. The second potential labor problem involves the skills and training required to produce the AAPS. The conversion to any unconventional AAPS will involve a degree of production personnel retraining.

However, if the engine is very complex, then the automobile industry may be faced with a general upgrading of skill levels and the introduction of new labor skills into the manufacturing process. This could raise the direct labor cost significantly. Therefore, it will be necessary to closely evaluate the AAPS candidates in terms of labor hours to produce and manpower skill levels required.

Distribution and sales personnel may be faced with a training cost, however, it is expected that these costs will be insignificant.

The above costs incurred by the industry will be passed on to the consumer in the purchase cost of the automobile. The purchase cost is the cost the consumer incurs when he purchases an automobile for cash, from a dealer. The purchase price of course depends on the make and model of automobile and, the optional equipment installed. In 1969, the average price of a new automobile was $3,510^{(19)}. This represents an increase of 15% over the average 1960 cost of $3,140^{(19)}. The primary cause of this increase was inflation; however, the addition of safety and emission control devices also contributed to the increase. During the 70's the purchase cost of automobiles is expected to increase as much as they have in the past. If we assume an average increase in cost due to 2% per year inflation, the average 1980 automobile will cost $4,350. The cost of emission control and safety devices must be added to this. It has been estimated that these costs will range between $300 and $700 per unit. If this is the case, the 1980 average automobile may cost over $5,000, representing a cost increase of approximately 40% above the 1969 average automobile purchase price.

Actual purchase price of the automobile is not necessarily a good measure for determining the cost impact to the consumer. A better measure would be the percent of median family income that an automobile purchase would represent. The average purchase price of an automobile has taken a decreasing percentage of the median family income since 1955 as shown in Figure 4. In 1968, the average new car purchase price represented 35% of the median family income. If we assume that income will continue to increase during the 70's as it did in the 60's, approximately 4% per year, a $5,000 automobile would represent almost 40% of the median 1980 family income. Looking at it another way, assuming the consumer is willing to spend the same percent of income in 1980 as he did in 1968, the average car could cost approximately $4,500.00 without creating a major consumer problem. This figure provides a first measure of comparisons.

The cost of an AAPS candidate should also be compared against the cost of the conventional internal combustion engine. A cost range for the IC engine and transmission was estimated for an average 1970 standard, 8 cylinder U. S. manufactured sedan(23). The baseline cost ranges are as follows:

	Minimum Cost	Maximum Cost
Power Converter (1)	$690	$1,010
Power Conditioner (2)	$160	$ 230

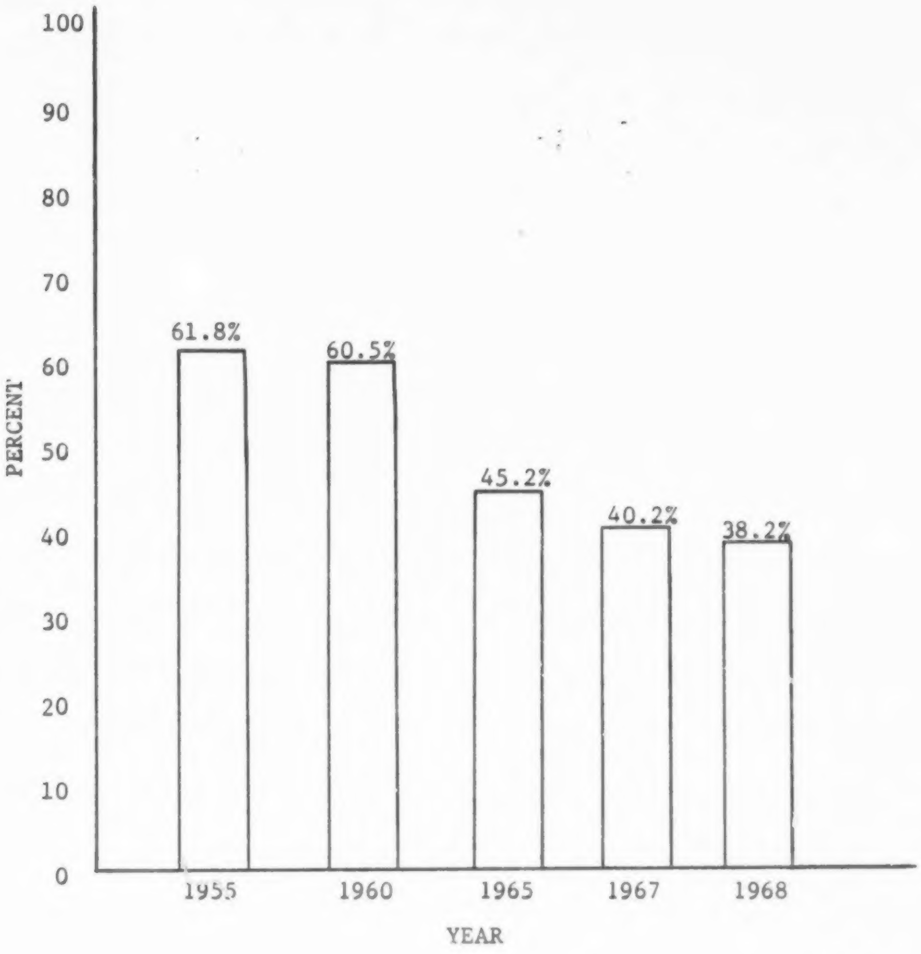


FIGURE 4

AVERAGE PRICE PAID FOR AUTOMOBILE AS A PERCENT OF MEDIAN FAMILY INCOME

(1) Average HP = 230 Weight = 690 lbs.

$$\text{Minimum} = \frac{\$3/\text{HP}}{3\ \text{lbs/HP}} = \$1.00/\text{lb.}^{(2)}$$

$$\text{Maximum} = \frac{\$4.40/\text{HP}}{3\ \text{lbs/HP}} = \$1.47/\text{lb.}^{(2)}$$

(2) Average HP = 230 Weight = 138 lbs.

$$\text{Minimum} = \frac{.70\$/\text{HP}}{.60\text{lbs/HP}} = \$1.17/\text{lb.}^{(2)}$$

$$\text{Maximum} = \frac{1.00\$/\text{HP}}{.60\#/\text{HP}} = \$1.67/\text{lb.}^{(2)}$$

3.3.2 Consumer Operating Cost

Automobile operating cost can be broken down into fixed and variable costs. The fixed cost, such as insurance, taxes, license and registration fees are not expected to change as a result of the operation of an advanced low-emission vehicle and therefore, will be treated as a constant in this study.

The variable costs are directly related to the power system, the number of miles driven, how hard the car is used and other factors and include the cost of the energy supply, lubrication, repair, maintenance, and replacement parts. The cost of tires are not expected to be affected by the operation of an advanced power system.

3.3.2.1 Fuel and Lubrication Cost. The cost of fuel and lubricant varies considerably among vehicles. Fuel consumption for the same make and model may vary as much as 50 percent since consumption depends on how the vehicle is driven, the type of driving (urban, highspeed cruise), the load carried and the general condition of the vehicle. Oil consumption also varies considerably among vehicles, and depends on essentially the same factors as does fuel consumption.

In 1969, passenger cars consumed 62,325 million gallons of gasoline. This represented an average of 13.63 miles traveled per gallon of gasoline consumed. Based on the August 1971 average price of gasoline of 24.6 cents/gallon excluding taxes, the cost per mile driven is $.0180.(20) The average cost of oil used in automobiles is approximately $.0016 per mile.

The consumer cost of fuel for a candidate AAPS will depend on the unit cost of the fuel and the miles which can be driven on a unit of fuel. If the AAPS candidate uses gasoline as a fuel, no major change in cost is expected. However, if the candidate uses another petroleum product such as kerosine or diesel fuel, some change in cost will most likely occur. The petroleum industry is currently producing annually 87.5 billion gallons of gasoline; 4.2 billion gallons of kerosine; 7 billion gallons of diesel fuel, and 13 billion gallons of jet fuel. Thus, any change from gasoline to one of the other common petroleum fuels will require a significant increase in the capacity of the industry to produce and distribute the fuel. The cost of this increased capacity will most likely be passed on to the consumer. Thus, while the other petroleum fuels are currently lower in cost than gasoline, (approximately $.01/gallon wholesale) it would be reasonable to expect a significant increase in the cost of these fuel if a major conversion from gasoline did take place. (An example of the cost of changing fuels can be seen in the $.01 - $.02/gallon increase in unleaded gasoline over leaded gasoline.) An adequate estimate of the cost of other petroleum fuels produced in 100 or more billion gallon quantities can only be developed after extensive analysis of the petroleum industry and refinery processes. To estimate consumer cost based on current prices of other petroleum fuels could lead to significant errors.

Estimating consumer fuel cost for AAPS candidates which require a non-petroleum energy supply will require extensive analysis. For example, the cost of the electricity needed to power a vehicle must be determined by analyzing the cost of additional generating capacity, fuel cost for the additional capacity, cost of recharging stations and others. Further, the cost estimate must consider the conversion costs for the existing 216,000 retail petroleum service stations.

The other factor which will influence the consumer fuel bill is the rate at which fuel is consumed by the engine. It has been estimated that a 10% loss in fuel performance will be one of the cost associated with IC engine emission control. If this is the case, the average motorist will buy on the average an additional 74 gallons of gasoline a year at a cost of approximately $27.00.

As a measure of comparison the following fuel cost baseline has been established. All costs are in 1971 dollars.

1971 Fuel Cost/Mile	$.018
Additional Cost due to unleaded gasoline	.0015
Additional cost due to lower performance	.0019
Baseline fuel cost $/mile	$.0214

No major change in oil cost is expected, therefore, the baseline remains at $.0016/mile.

3.3.2.2 Maintenance, Repairs and Replacement Parts. Maintenance and repair cost vary primarily as a result of total miles driven, the age of the vehicle and the original purchase price of the vehicle. The first year maintenance and repair cost are generally low due to the newness of the vehicle and the fact that manufacturers parts and labor warranties are in effect. As the automobile gets older, these costs increase significantly as shown below(19).

YEAR	MILES DRIVEN	$/MILE	TOTAL COST
1	14,500	.005	72.50
3	11,500	.0159	183.00
5	9,900	.0174	272.00
7	9,500	.0340	322.00

The 10-year total cost for maintenance and repairs is approximately $1,900.00 or 54% of the average price paid for the car.

The conversion to an AAPS power automobile may have a most pronounced effect on the automobile parts and service industry. This is primarily due to its magnitude and complexity. The complexity of the industry is illustrated in Figure 5. Automobile manufacturers

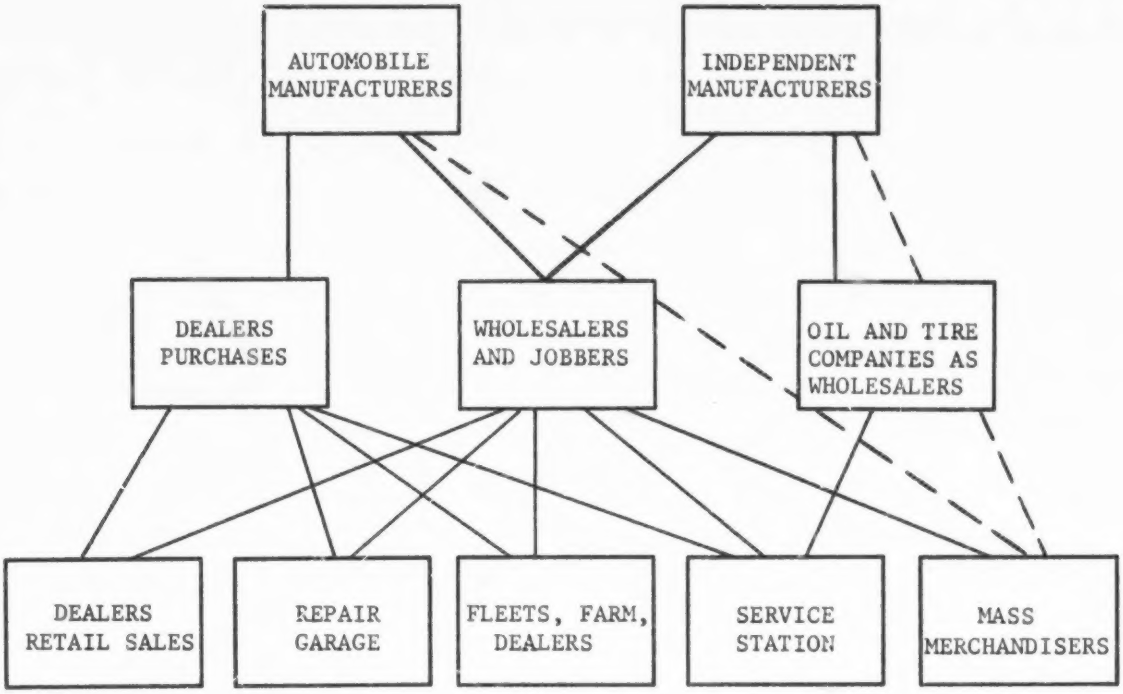

AUTOMOBILE MANUFACTURERS
INDEPENDENT MANUFACTURERS
DEALERS PURCHASES
WHOLESALERS AND JOBBERS
OIL AND TIRE COMPANIES AS WHOLESALERS
DEALERS RETAIL SALES
REPAIR GARAGE
FLEETS, FARM, DEALERS
SERVICE STATION
MASS MERCHANDISERS

FIGURE 5

STRUCTURE OF AUTOMOTIVE PARTS DISTRIBUTION (25) make about 30% of parts sold to the after-market, distributing most of these to dealers and the remainder to wholesalers, and mass merchandisers. Independent manufacturers account for the remaining 70% of the parts after-market. They sell mostly to wholesalers and jobbers with the remaining going to mass merchandisers.

The magnitude of the service industry is shown in the following Table.

RETAIL SALES - SERVICE

Type of Business	Number of Establishments	Number of Employees (000)	SALES (Billions)		
			Parts	Labor	Total
New Car Dealers	32,898	696	4.8	2.4	7.2
Tire Battery & Accessory Dealers	29,189	130	2.4	1.8	4.2
Gasoline Service Stations (1)	216,058	800	2.4	1.1	3.5
Automobile Repair Shops	109,946	298	2.5	1.8	4.3
TOTAL Retail-Serivce	385,091	1,914	12.1	7.1	19.2

(1) Does not include sales of gasoline and oil.

The total 1967 outlay by consumers for automobile services represented approximately 4 percent of all consumer expenditures.

Conversion to an AAPS places two burdens on this industry:

(1) cost of maintaining inventories for the IC engines and the AAPS,

(2) training or retraining maintenance personnel.

There are over 100,000(25) separate parts listed for automobiles. This inventory of parts will have to be maintained in the service industry for approximately 10 years after the IC engine production is terminated. An inventory of parts for the AAPS will have to be manufactured and distributed during this time. This could result in increased inventory costs to the service industry which would be passed on to the consumer in higher maintenance and repair bills.

Training cost for mechanics may represent a very significant cost of conversion. It is estimated that the entire service industry employed 875,000(17) mechanics in 1971 and that the number of mechanics will grow to 940,000(17) in 1975. Government training costs in 1970 for mechanics range between $620 to $2,900(25) depending on the needs of the trainee, training program design and the skill level required. Assuming the lowest cost, 90 day retraining program, the total cost of retraining the 1975 mechanic population would approach $600 million. This cost will have to be absorbed by the consumer in terms of higher labor charges or by the Government and eventually by the taxpayer.

For a comparative evaluation of repair and maintenance costs of AAPS a baseline has been established. This baseline includes cost of labor and replacement parts, and an estimate of the increased maintenance cost due to new emission control and safety devices to be installed on automobiles during the 1971-1975 period.

1970 cost/mile	-	$.0191
Cost increases due to increased complexity of IC engine, emission controls, safety features (15%)	-	.0029
TOTAL Maintenance, Repair and Replacement Parts Baseline		.0220

3.3.2.3 Insurance, Taxes and Fees. The cost of insurance, taxes and fees are not expected to change as a result of the conversion to an AAPS. These costs are therefore held constant at the 1970 level as follows.

Insurance	$.0172/mile
Taxes and fees	$.0135/mile
	$.0307

3.3.2.4 Summary. The 1970 nationwide average total operating costs, excluding depreciation, for a 4-door sedan driven 100,000 miles over ten years is $.069/mile. The baseline operating cost for evaluation purposes is compared to the 1970 costs in the following Table.

	1970	Evaluation Baseline
Fuel	.0173	.0214
Oil	.0016	.0016
Maintenance & Repair & Replacement Parts	.0191	.0220
Accessories	.0003	.0003
Insurance	.0172	.0172
Taxes & Fees	.0135	.0135
	.069	.076

3.4 Economic Reallocation

The economic reallocation factor is defined as a shifting in the allocation of resources from one industry to another and, in the extreme, abandonment of part or an entire industry. Economic reallocation principal effects are displacement of the labor force, premature obsolence of plant and equipment in some industries and severe shortages in trained personnel, plant and equipment in other industries.

Economic reallocation caused by the conversion to an AAPS will be the most difficult factor to evaluate and the one most subject to error.

Economic reallocation should be evaluated for each of the major segments of the automotive industry, including manufacturing, wholesale trade, and retail service and trade.

3.4.1 Manufacturing

The value of automobiles shipped from the manufacturing industry in 1971 is expected to be approximately $24 billion(25). This accounts for approximately 2% of the projected gross national product.

A single industry of this magnitude has an effect on many industries in the economy. For example, in 1967, the cost of materials used in the motor vehicles industry amounted to $19.9 billion. A partial list of these materials are shown in Table I. Table II illustrates the automotive industries consumption of metals. As can be seen from these tables, the motor vehicle industry consumes a large percentage of the total production of several other manufacturing industries.

TABLE I

AUTOMOTIVE PARTS AND COMPONENTS MANUFACTURING ENGINE RELATED INDUSTRY(22)

SIC*	INDUSTRY	QUANTITY	VALUE $M	% OF TOTAL INDUSTRY
28993	Chemical Preparations - Anti Freeze and Others	NA	160.2	14
30691	Rubber and Plastic Belts (million units)	59.9	41.6	16
35991-11	Carburetors (million units)	15.2	177.1	NA
35991-31	Pistons-Aluminum (million)	38.0	70.6	NA
35991-35	Pistons-Other (million)	2.0	1.5	NA
35991-51	Piston Rings Oil (million)	257.4	31.4	NA
	Piston Rings Compression (million)	437.8	55.1	NA
35991-61	Valves (million)	131.4	80.9	NA
3621	Motor and Generators (Accessory) (million)	28.	145.6	6.3
3691	Storage Batteries (million)	40.7	364.4	63
3694	Ignition harnesses (millions)	24.2	33.3	NA
	Generators 6V (millions)	NA	2.1	NA
	12V (millions)	11.6	156.3	NA
	Rebuilt Generators	NA	27.0	NA
	Rebuilt Regulators	NA	.9	NA
	New Regulators	15.1	41.4	NA
	Cranking Motors New	11.7	197.7	NA
	Cranking Motors Rebuilt	2.6	23.5	NA
	Spark Plugs	656.2	184.8	NA

NA = Not Available.

*SIC = Standard Industrial Code

TABLE I (CONT'D)

SIC*	INDUSTRY	QUANTITY	VALUE $M	% OF TOTAL INDUSTRY
3694	Ignition Coils	16.0	30.0	NA
	Distributors	11.6	69.6	NA
	Auto Switches	124.3	120.7	NA
	Components & Parts (points, condensers, rotors, etc.)	NA	150.7	NA
	TOTAL VALUE OF ENGINE RELATED INDUSTRY SHIPMENTS		2,156.4	

TABLE I (CONT'D)

BODY, CHASSIS, SUSPENSION TIRES AND OTHERS

SIC	INDUSTRY	QUANTITY	VALUE $M	% OF TOTAL INDUSTRY
22960	Tire Cord & Fabric (million lbs)	478.6	404.6	NA
30695	Mechanical Rubber Goods (million lbs)	N/A	204.3	19
30795	Industrial Plastic Products	N/A	305.6	24
32113	Laminated Glass million ft^2	190	342.0	94
32292	Lighing & Electrical Glassware	N/A	17.1	5
32315	Mirrors	N/A	41.7	26
32316	Tempered Glass million ft^2	86.3	59.1	58
33579	Non Ferrous Wiring (million lbs copper)	22.5	25.8	.7
28516	Industrial Product Finishers (million gal)	40.7	119.4	17
28517	Industrial Lacquers (million gal)	12.0	40.3	22
30111	Tires & Inner Tubes (million)	172.4	1,753	56
34231	Hand Service Tools (million)	7.6	24.5	6
3429	Misc. Hardware	N/A	807.7	36
3451	Screw Machine Products	N/A	233.2	23
3452	Bolts, Nuts, Rivets	N/A	91.2	6
3461	Metal Stampings	N/A	3,178.2	58
34819	Wire Chain (1000 tons)	44.6	38.6	43
3493	Steel Springs (1000 tons)	417.8	164.2	62
3585179	Air Conditioning (000 units)	3190	327.6	N/A
3641	Electric Lamps (000 bulbs)	592.8	88.2	12

TABLE I (CONT'D)

3642	Lighting Fixtures	N/A	167.6	11
3651	Radio & TV Receiving Sets (million)	8.2	211.1	6
38214	Motor Vehicle Instruments	N/A	71.4	N/A
	TOTAL VALUE OF BODY CHASSIS, SUSPENSION, TIRE and OTHER AUTOMOTIVE SHIPMENTS		8,716.4	

TABLE I (CONCLUDED)

AUTOMOTIVE INTERIOR FINISHING

SIC	INDUSTRY	QUANTITY	VALUE	% OF TOTAL INDUSTRY
22720-05	Tufted Carpets & Rugs Million yds^2	40.2	84.6	6.4
22930-13	Padding and Upholstry Filling (million lbs)	2.6	60.1	37
23962-16	Automotive and Apparel Trimming		513.	64
23990	Fabricated Tensile Products (1000 sets)	32,777	98.0	18
30693	Sponge & Foam Rubber Goods (million lb)	43.5	45.5	16
30694	Rubber Floor & Wall Covering	N/A	28.8	40
34813	Misc. Wire Spring Products (1000 tons)	188	114.4	45
TOTAL VALUE OF AUTOMOTIVE INTERIOR FINISHING SHIPMENTS			944.4	

TABLE II

AUTOMOTIVE INDUSTRY MATERIAL CONSUMPTION (1968)

INDUSTRY	NATIONAL CONSUMPTION	1968 AUTOMOTIVE INDUSTRY CONSUMPTION	% OF U.S. CONSUMPTION
1. Steel (tons)			
Alloy bar	7,815,606	1,740,301	22.3
Stainless bar	819,042	132,174	16.1
Carbon bar	1,677,641	1,023,347	60.9
Total bar	10,312,289	2,895,822	28.1
Strip	3,010,911	829,772	27.6
Sheet	27,117,391	12,470,266	46.0
Galvanized	5,201,099	943,295	18.0
Total Steel	91,855,894	19,269,373	21.0
2. Aluminum (tons)	5,043,500	522,500	10.4
3. Copper & Copper Alloys (ton)	3,188,500	260,500	8.2
4. Gray and Ductile Iron (ton)	15,672,000	2,927.000	19.4
5. Lead (tons)	1,328,770	723,443	54.7
6. Malleable Iron (tons)	1,093,788	437,540	40.0
7. Nickel (tons)	170,000	42,230	14.3
8. Rubber (tons)	3,040,586	1,967,508	64.7
9. Zinc (tons)	1,550,000	566,000	36.5

The AAPS cost analysis must consider the prospects of a major shift away from one of these manufacturing industries, and the impact that this shift would cause on the overall economy. For example, an AAPS which requires the shift to electricity rather than gasoline as an energy source must be evaluated in the light of the 437 gasoline manufacturing establishments employing 106,700 people and having sales in excess of $20 billion.

In order to adequately assess the impact of conversion to an AAPS on other industries a detailed study must be made of the materials and the component manufacturing needed to produce the AAPS. The results of this study should then be compared against an IC engine manufacturing baseline such as that contained under Engine Related Industries - Table I and the Material Consumption - Table II. An index of manufacturing reallocation can then be established for each candidate AAPS, and a rank ordering of all candidates can be made in terms of value and economic reallocation impact.

3.4.2 Wholesale Trade

The automotive wholesale trade would probably be minimally affected by a conversion to an AAPS candidate. Even though this segment is large (65,700 establishments, 550,000 employees, $80 billion sales) no major change in the wholesalers basic function can be seen. The one exception is the petroleum wholesalers which would be significantly affected if the AAPS uses an energy source other than gasoline.

3.4.3 Retail and Service

This segment of the automotive industry would potentially have the largest problem in converting to the AAPS. This segment is characterized by the large number of relatively small independent business establishments as shown below:

	NUMBER OF ESTABLISHMENTS	EMPLOYEES	SALES ($ MILLION)
Motor Vehicle Dealers	62,023	785,900	48,635.6
Tire, Battery & Accessory Dealers	29,189	158,800	4,235.8
Gasoline Service Stations	216,059	800,300	22,709.4
Auto. Repair Shops	109,946	297,069	4,085.5
TOTAL	417,217	2,042,069	79,666.3

Many of these businesses are one, two or three man operations. For example of the 109,946 automobile repair shops, approximately 48,000 have no employees. Only 44,000 of the 62,000 motor vehicle dealers have paid employees.

The problem facing this segment of the industry is one of survival. Many of these businesses have low dollar volume of sales and low working capital to invest in tools and equipment which may be necessary to make the conversion. A survey of the yearly salary volume averages for repair shops illustrates this problem. The results of the survey showed the percentage repair shops having an average annual dollar volume as follows: $300,000 and over, 1.3%; $200,000 - $299,999, 1.9%; $150,000 to $199,000, 3.3%; $100,000 to

$149,999, 8.2%; $80,000 to $99,999, 5.2%; $60,000 to $79,99, 10.0%; $40,000 to $59,999, 16.0%; $20,000 to $39,999, 28.5%; $0 to $20,000, 25.6%.(25)

Another problem is the possible loss of mechanics which constitute a large portion of the labor employed in this segment. On the average, mechanics earn about $6,500/year. If they are faced with paying for retraining (estimated minimum cost $620) and purchasing additional tools necessary to repair an AAPS, many mechanics may leave the industry for better paying jobs. If this occurs, the mechanic to vehicle ratio may increase significantly above the 1 mechanic to 154 vehicles projected for 1975 and, consequently increase repair costs and decrease availability of repairs.

AAPS candidates must be evaluated in the terms of the above considerations. A massive disruption of the retail and service industry would have a significant impact on the economy and the social well being of the nation.

3.5 Cost to Governments

Federal, State and Local Governments receive considerable revenues from taxes on automobiles and gasoline. In 1969 these tax revenues were as follows:(18)

Government Revenues (Millions)

	Federal	State	Total
Fuel Receipts	3,350	5,977	9,327
Oil	59		59
Tires	572		572
Tread Rubber	29		29
Automobiles	1,874		1,874
Trucks, Busses, Trailers	629		629
Parts & Accessories	82		82
Motor Vehicle Tax	134	166	300
Registration Fees		2,564	2,564
Other Fees		534	534
TOTAL	6,728	9,234	15,969

Candidate AAPS should be evaluated to determine if a substantial change in these receipts would occur under existing tax structures.

All units of government are responsible for capital outlays and maintenance of the nation's highway system. In 1969, government disbursements for highways amounted to approximately $18,382 million. These disbursements have been increasing at a rate of approximately 7% per year. Candidate AAPS could influence new highway designs and require modification to existing highways. Therefore, the candidate AAPS should be analyzed to determine any effect which it might have on the nation's highways and the associated cost to the governments, and eventually, the taxpayer and consumer.

There may be other costs to the governments which must be considered. For example, periodic inspection of privately owned vehicles to insure they do not exceed emission standards may become the responsibility of one of the levels of government. Large expenditures for research and development, demonstration and fleet testing by federal and state governments may have an impact on the taxpayers. These and other potential cost to governments must be analyzed in evaluating the candidate AAPS.

SECTION IV

AAPS STRUCTURED VALUE ANALYSIS MODEL

4.0 INTRODUCTION

This section presents the analytical formulation of the AAPS Structured Value Analysis Model. Included are the value judgment curves and value function for the parameters discussed in Section 2.0, the value sets for each of the eight evaluation categories and the total AAPS system value set.

The value function and its graphic representation, the value judgment curve, is the basic input to the AAPS Structured Value Analysis model. The value function relates points on the parameter measurement scale to a value scale which ranges between zero for no value to the user and unity for maximum value to the user. In this case the user is DAAPSD acting as agent for the motoring public.

Category value sets for the eight evaluation categories are also presented. These value sets establish the relationship among the parameters in a particular category. Finally an AAPS system value set presented which establishes the relationship among the eight evaluation categories is defined.

4.1 Value Functions

The value function relates points on the parameter measurement scale to a normalized value scale which ranges between zero for no value to unity for maximum value and is graphically represented by a value judgment curve. Figure 6 shows a typical value judgment curve.

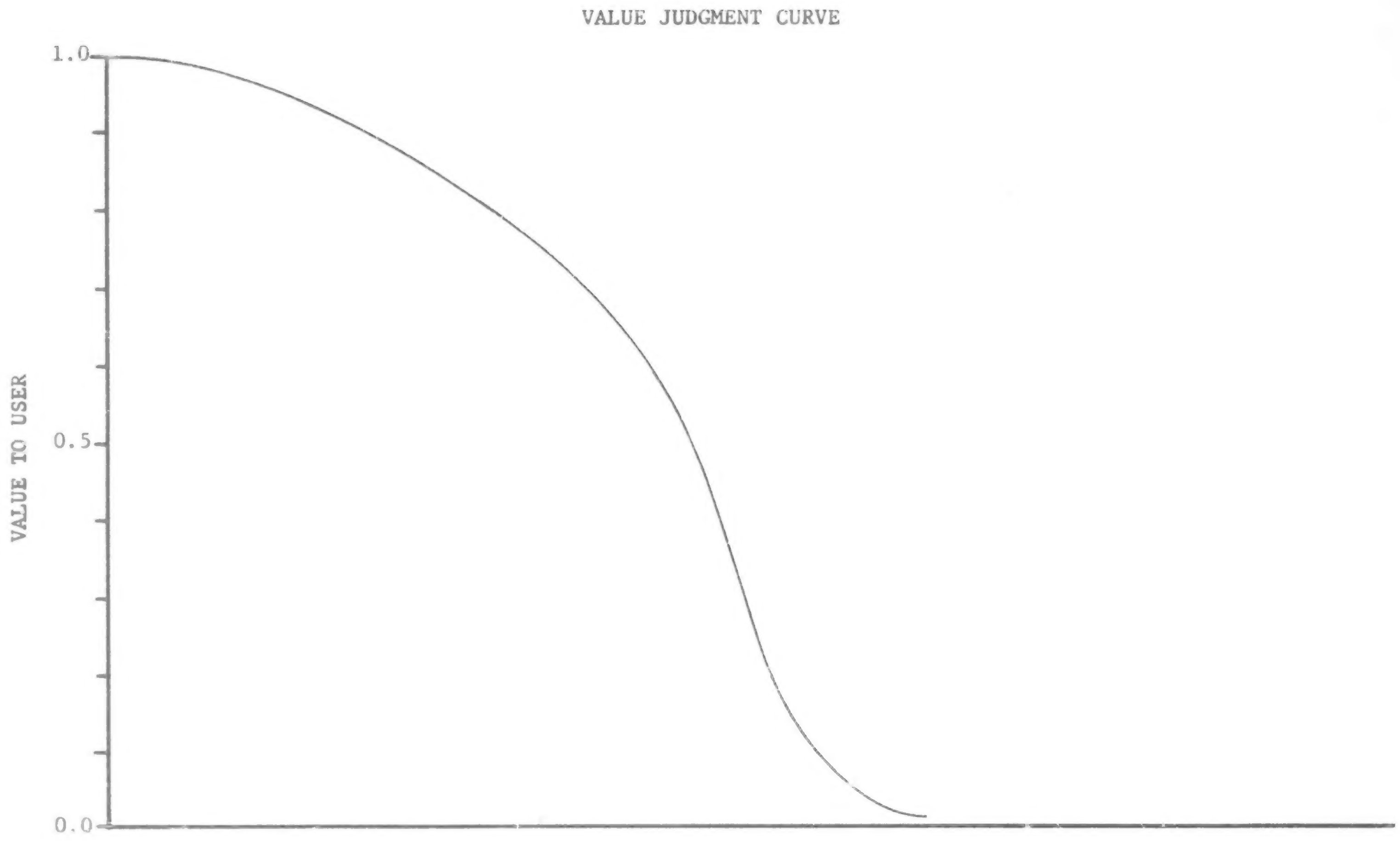


FIGURE 6

LEVEL OF PERFORMANCE

With each level of performance there is associated some value on a scale from 0 to 1, where 1 corresponds to a level of performance beyond which no further value accrues. Similarly, the 0 value corresponds to the level of performance which is beyond the range of acceptability and thus has no value to the DAAPSD and/or to the automobile consumer.

4.1.1 Value Judgment Curve Development

A common approach was used to develop the value judgment curves contained in this section. This approach resulted in value judgment curves with the following desirable characteristics:

1. smooth variation over the entire range,
2. zero slope at the origin,
3. asymptotic approach to zero or one for large values of the parameters, and
4. flexibility so that special cases are easily incorporated.

The first step in developing the value judgment curve was to establish the maximum and minimum values for each evaluation parameter. These maximums and minimums were presented in Section 2.0 of this report. The next step was to define any additional points between the parameter maximum and minimum points and to assign a value to these points. For example, four points along the measurement scale for the carbon monoxide emissions evaluation parameter were identified, and assigned a value as follows:

	PARAMETER VALUE	VALUE TO USER
1975 California Goal	12 grams/mile	.10
N. Y. City Goal	9 grams/mile	.25
Clean Air Act Standard	3.4 grams/mile	.95
DAAPSD Goal	3.4 grams/mile	.95

These points were then plotted on an initial value judgment scale and were joined through linear segments as shown in Figure 7.

Based on the linear plots, smooth curves with the desirable characteristics discussed above were developed. These curves approximate the linear curve throughout the entire range and are represented mathematically by one of the following functions:

$$v = \tanh \alpha x^n$$

or

$$v = 1 - \tanh \alpha x^n$$

where v = value to user

x = parameter value

$n > 1$

As a result of applying the function $1-\tanh \alpha x^n$ to the above CO emission example, the value judgment curve shown in Figure 8 was developed. This curve was reviewed by DAAPS and other automotive experts. As a result a new curve with increased slope and reduced range was agreed upon as being more representative of the CO emission/value to the user relationship. This curve is shown in Figure 9. This procedure was followed in the majority of cases.

The parameters which are measured by nominal scales could not be handled with this technique. The value judgment curves for the nominal scale parameters have a similar shape to those using the above

VALUE JUDGMENT CURVE

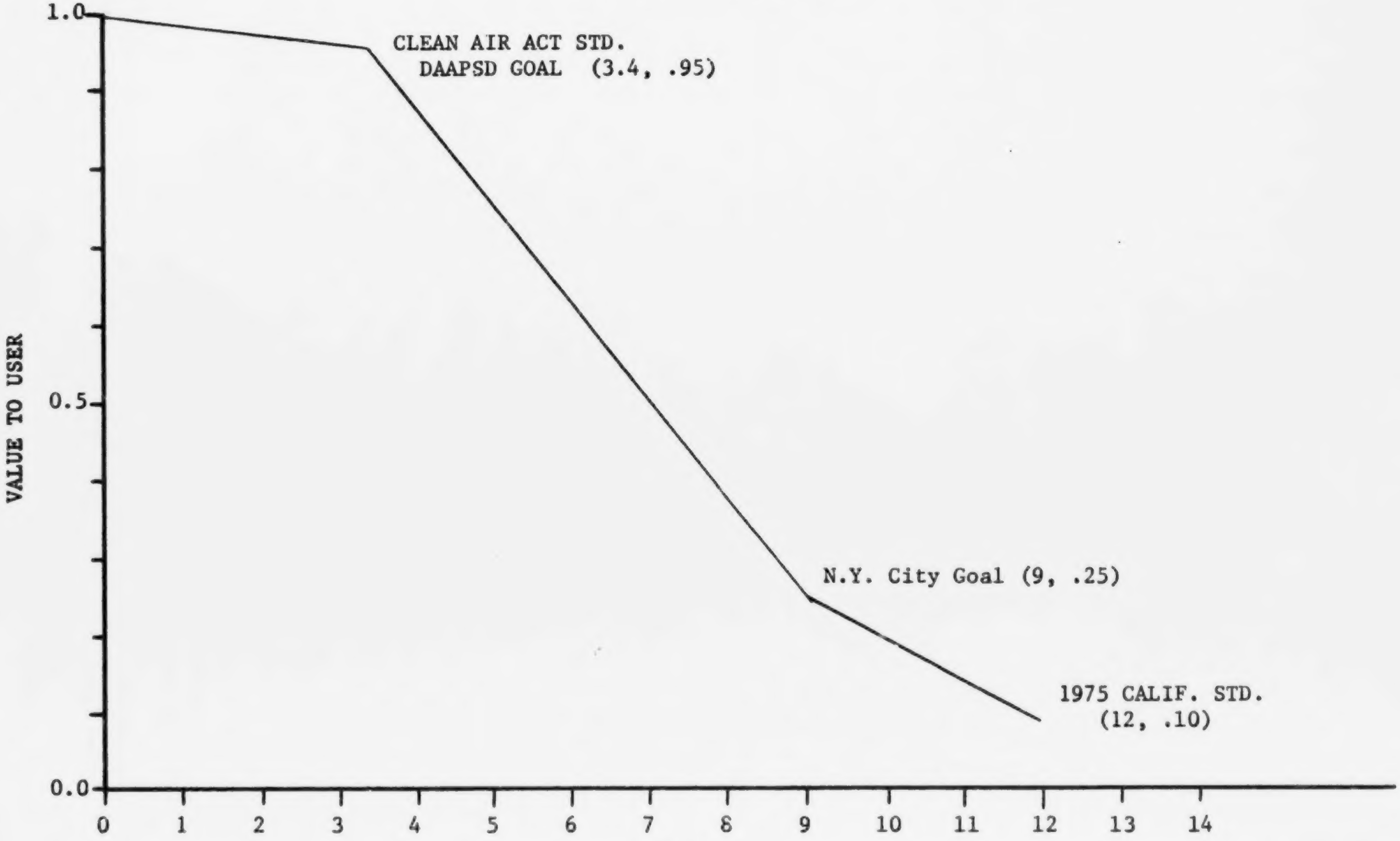


FIGURE 7
CO EMISSIONS
GRAMS/VEHICLE MILE

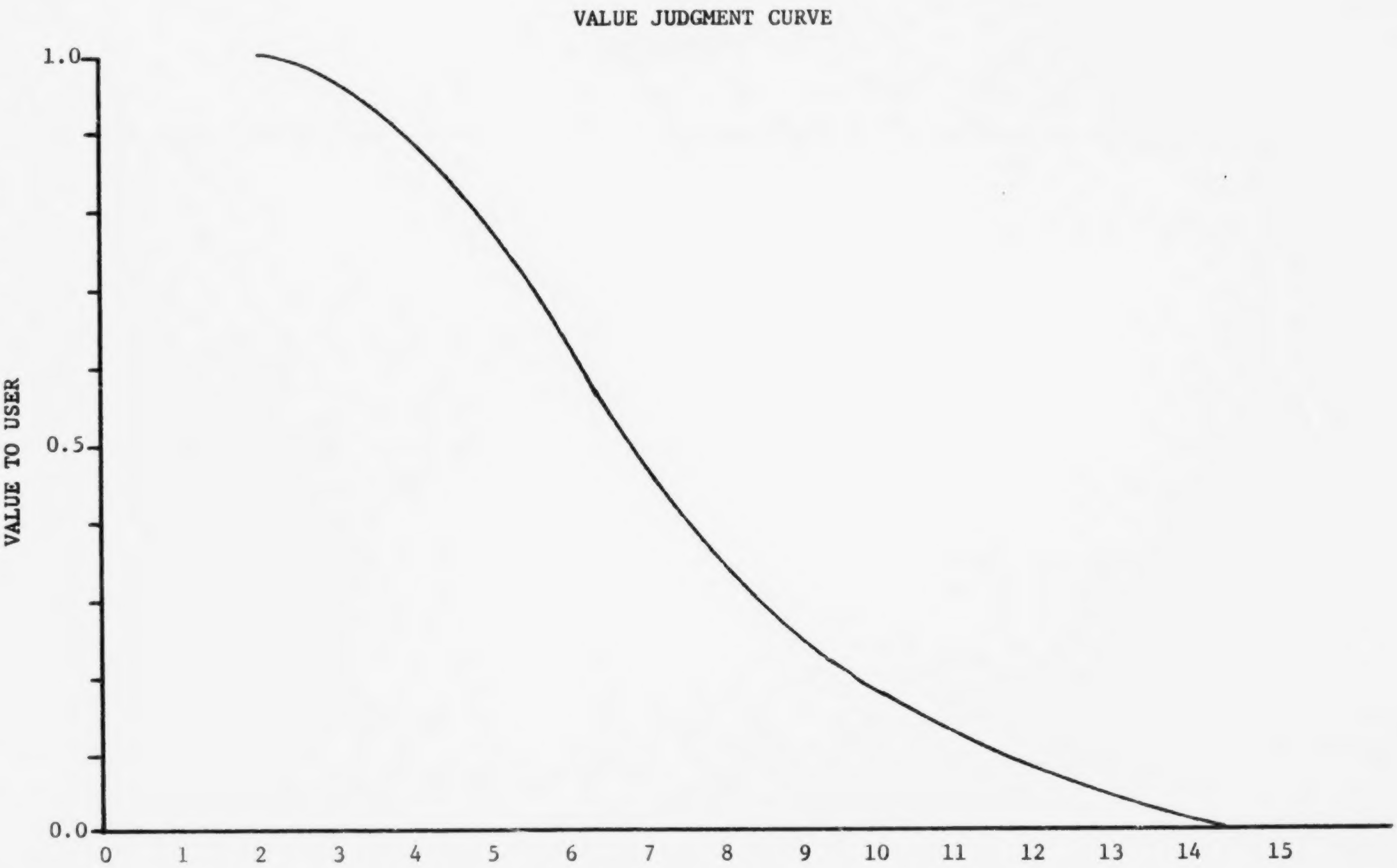


FIGURE 8
CO EMISSIONS
GRAMS/VEHICLE MILE

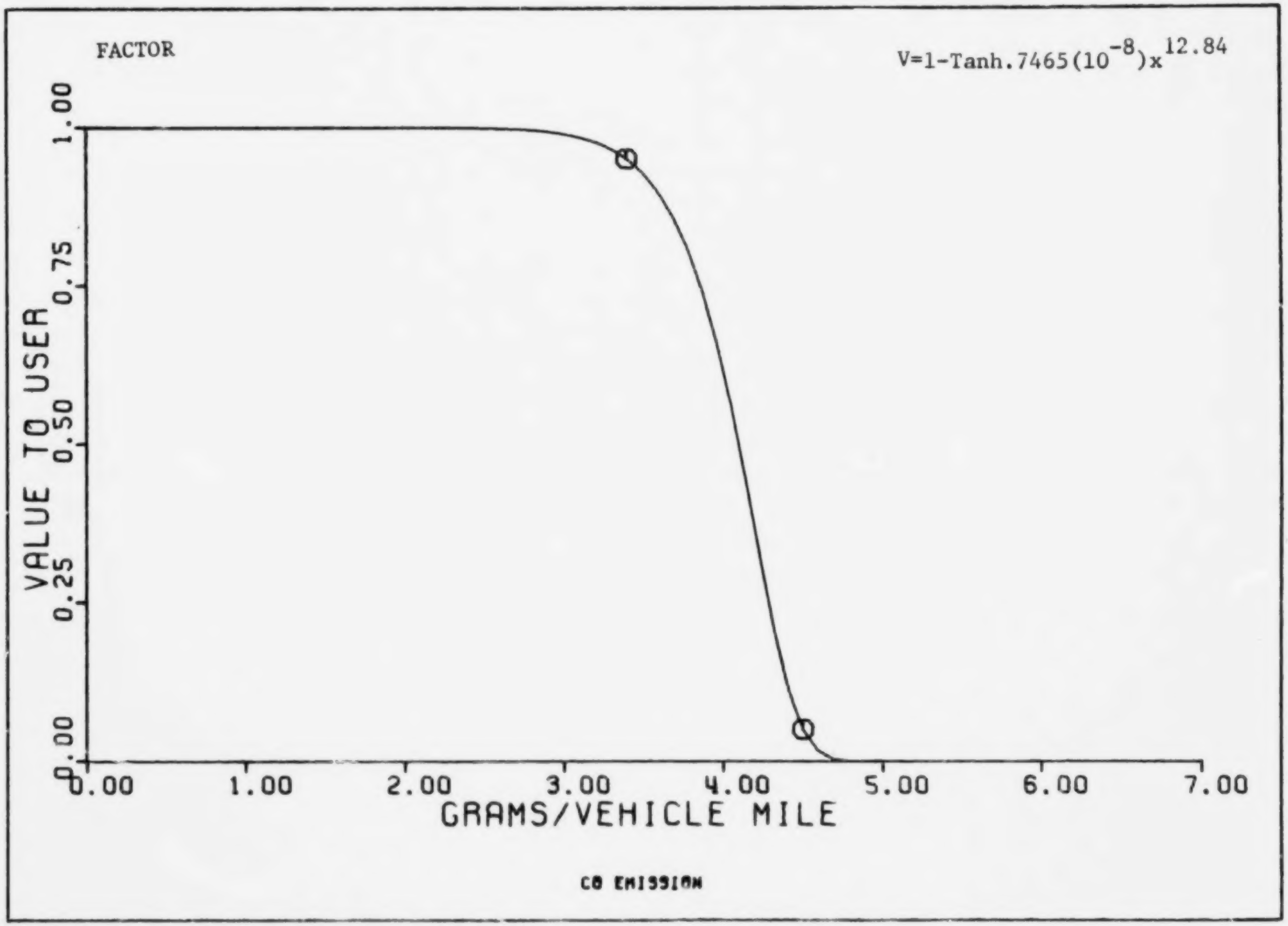


FIGURE 9

CO EMISSIONS
GRAMS/VEHICLE MILE

functions. However, a range of values are indicated on the curves which represent examples discussed in the Section 2.0 Evaluation Parameters. This range will allow the evaluator to judge the position of the candidate system with respect to the examples, and assign a value which would not be restricted to three or four discrete values. An example of this type of value judgment curve is shown in Figure 10.

Value judgment curves for 91 evaluation parameters are presented in the following sections. The shapes of the curves are based on available analytical data, and the judgment of DAAPSD and MITRE personnel. The equations for each curve are also presented. These equations are the value functions used in the Structured Value Analysis model to calculate the "Value to the User" corresponding to a measured parameter value. The two points shown on each curve are control points used in modifying the curve slope.

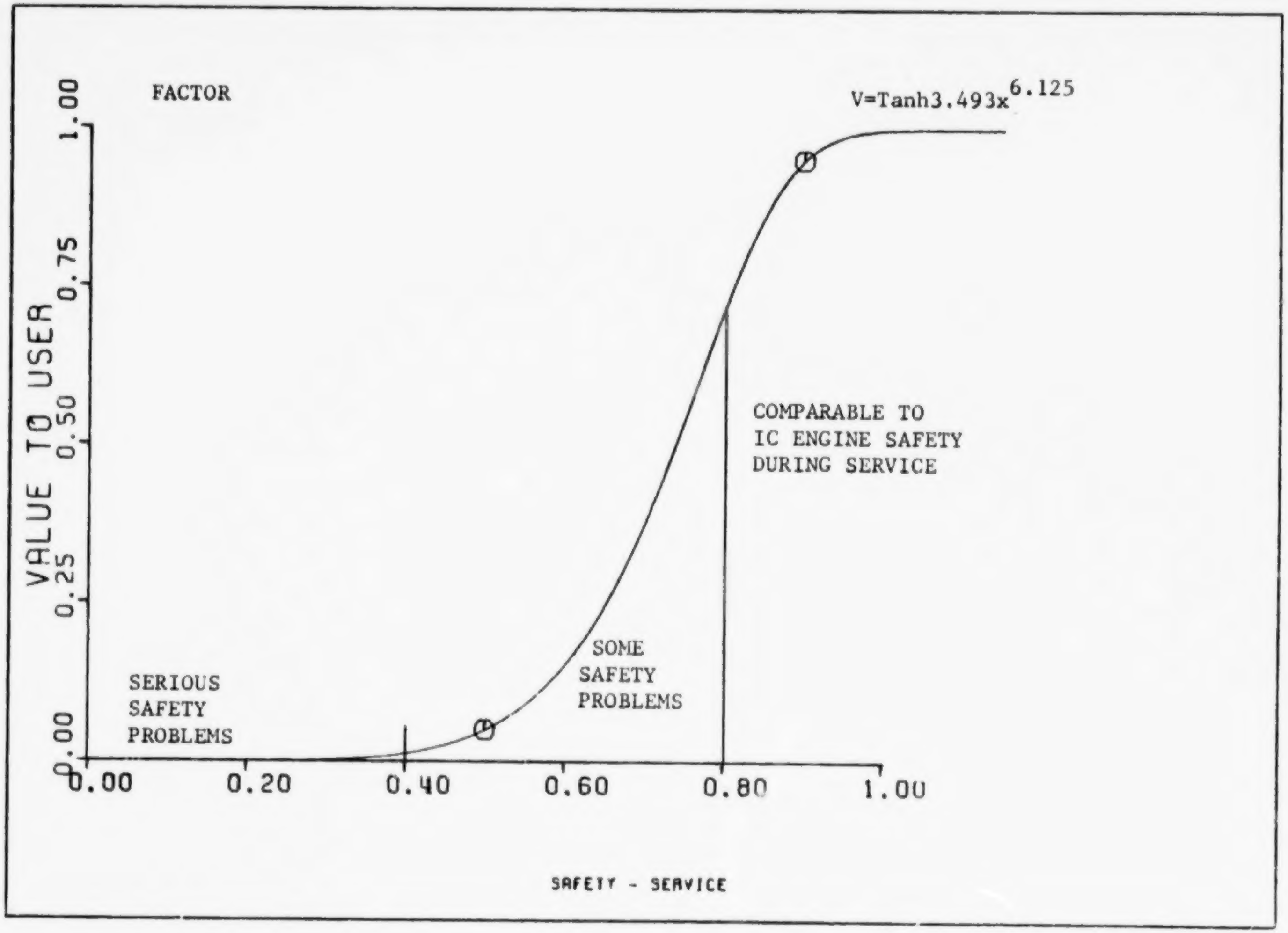
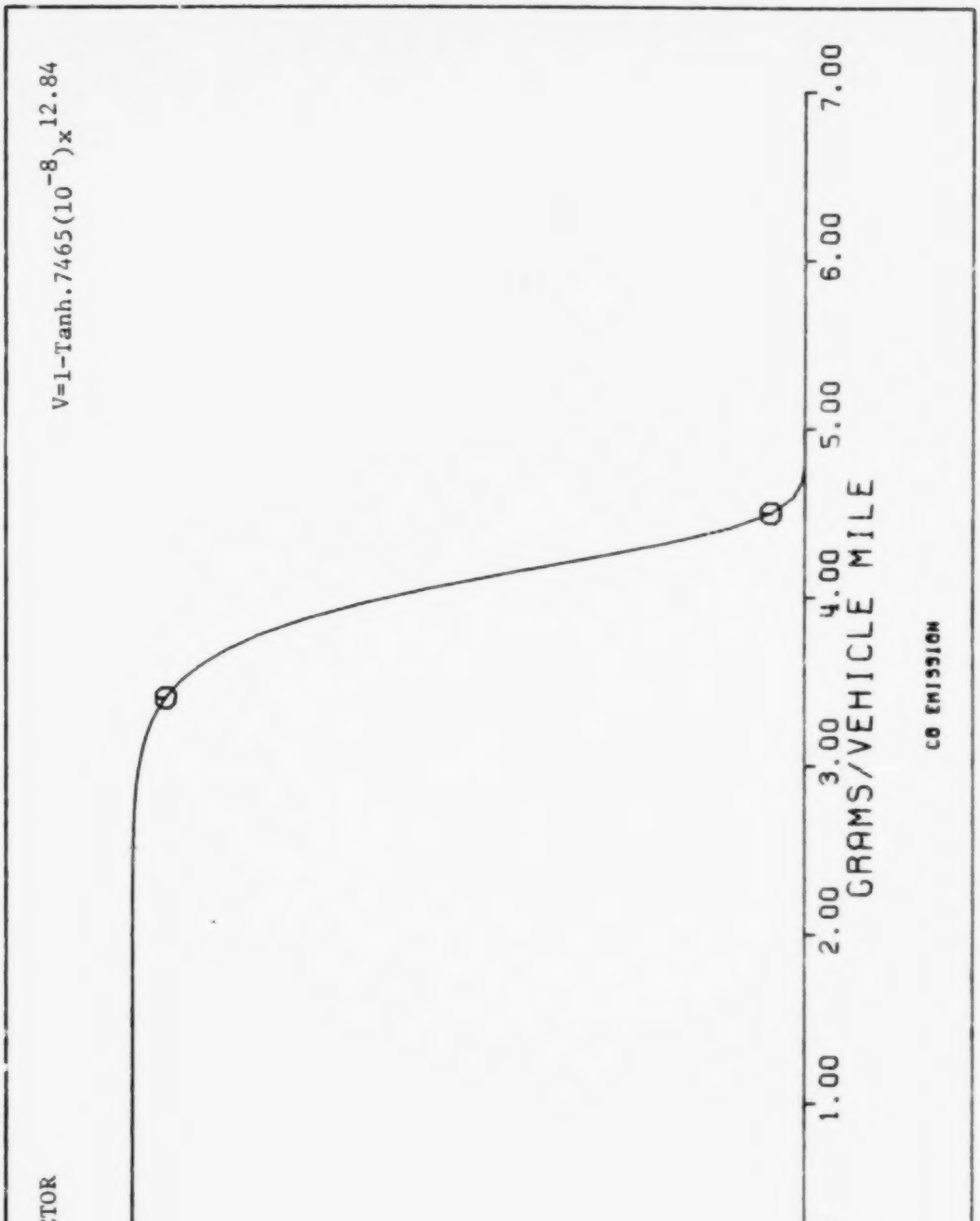


FIGURE 10

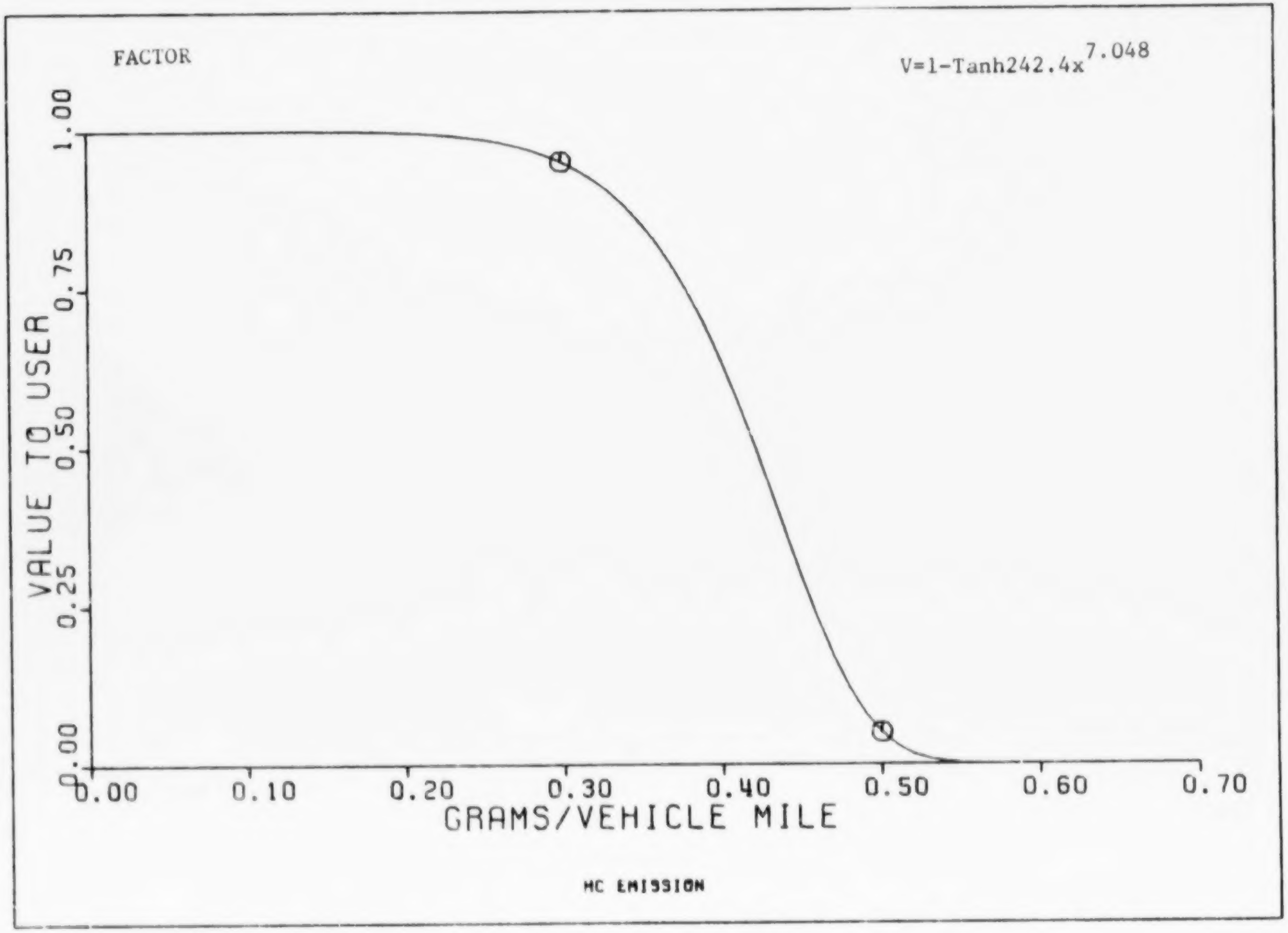
COMPLEXITY OF PRODUCTION CHANGEOVER

4.1.2 Emissions Category

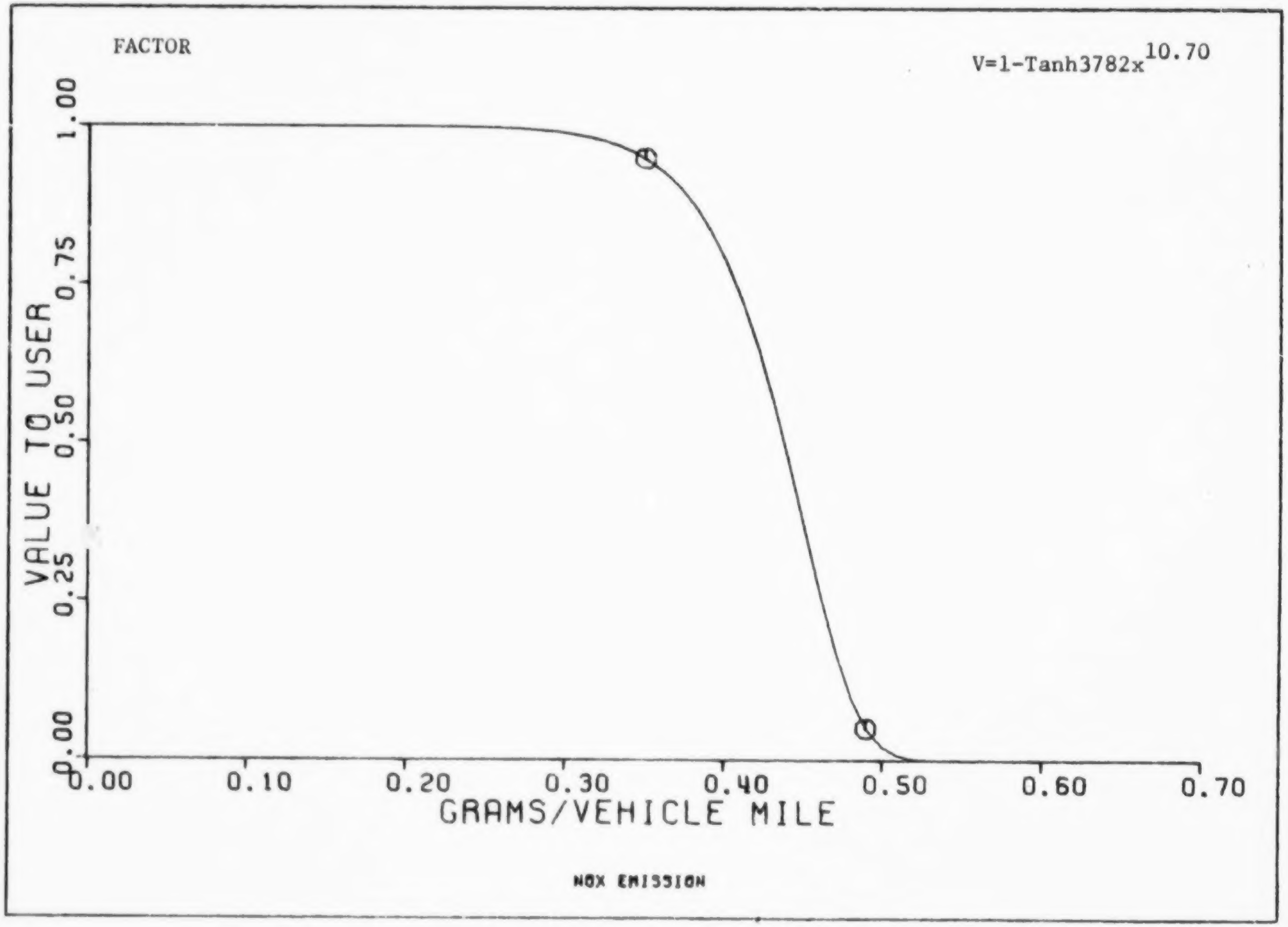
Carbon Monoxide Emission - Curve 1.1
Hydrocarbon Emission - Curve 1.2
Oxides of Nitrogen Emission - Curve 1.3
Sulfur Oxides Emissions - Curve 1.4
Particulates - Curve 1.5
Smoke - Curve 1.6
Odor - Curve 1.7
Maximum External Noise - Curve 1.8
Maximum Idle Noise - Curve 1.9
Maximum Low Speed Noise - Curve 1.10
Internal Noise - Curve 1.11


FACTOR
V=1-Tanh.7465(10^-8)x^12.84
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
GRAMS/VEHICLE MILE
CO EMISSION

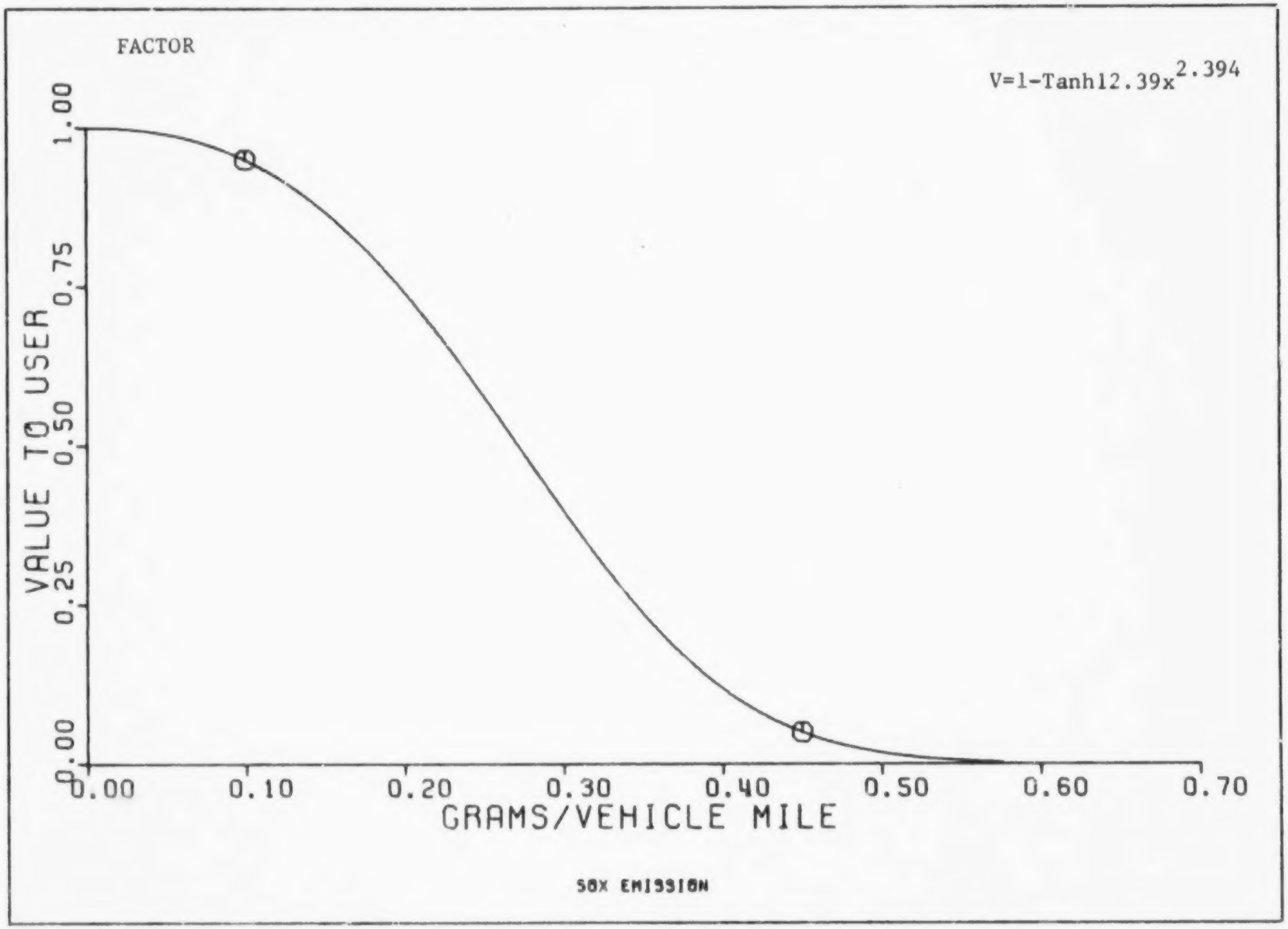
CURVE
1.1


FACTOR
V=1-Tanh242.4x^7.048
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
GRAMS/VEHICLE MILE
HC EMISSION

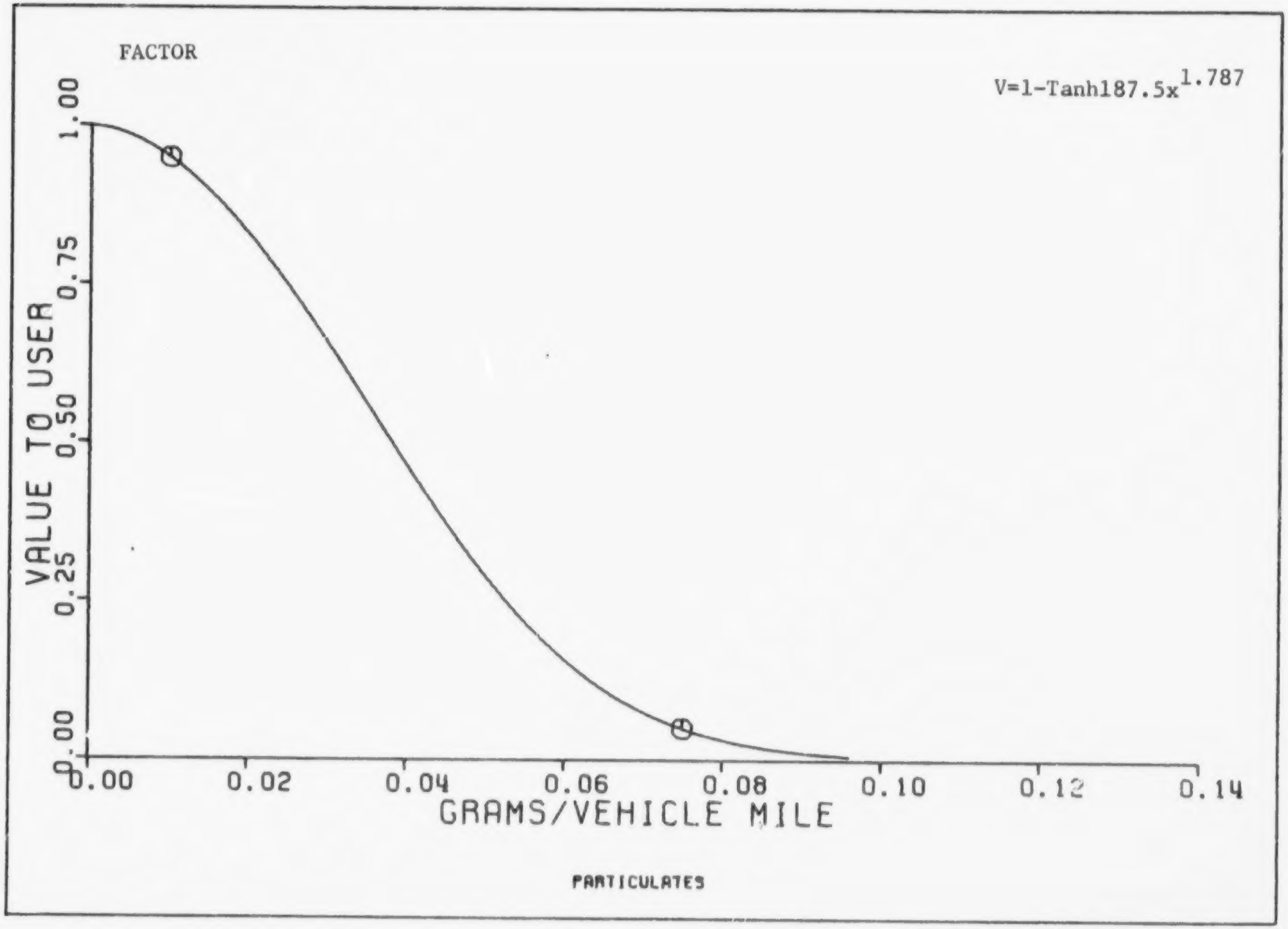
CURVE
1.2


FACTOR
$V=1-\mathrm{Tanh}3782x^{10.70}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
GRAMS/VEHICLE MILE
NOX EMISSION

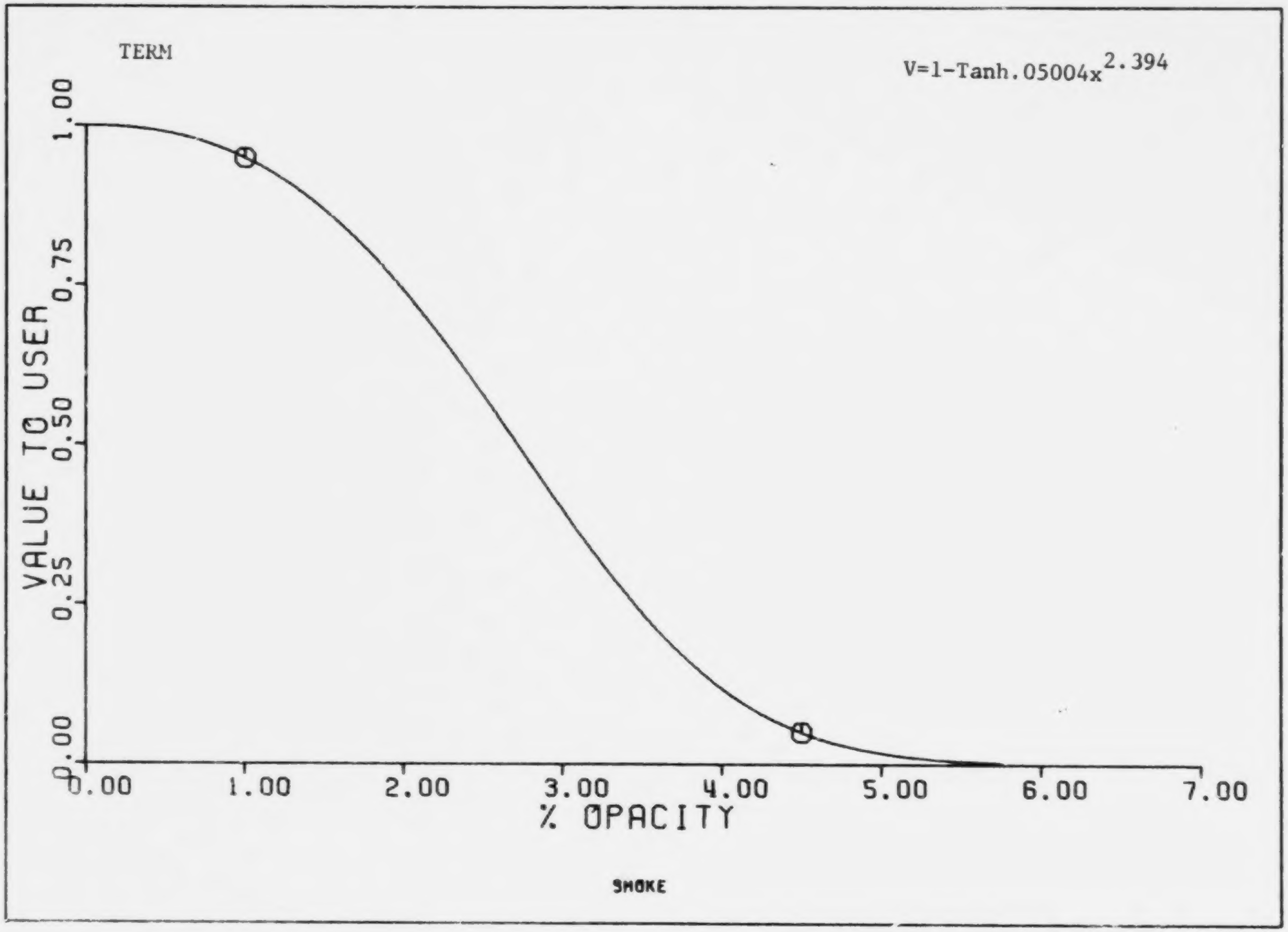
CURVE
1.3


FACTOR
V=1-Tanh12.39x^2.394
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
GRAMS/VEHICLE MILE
SOX EMISSION

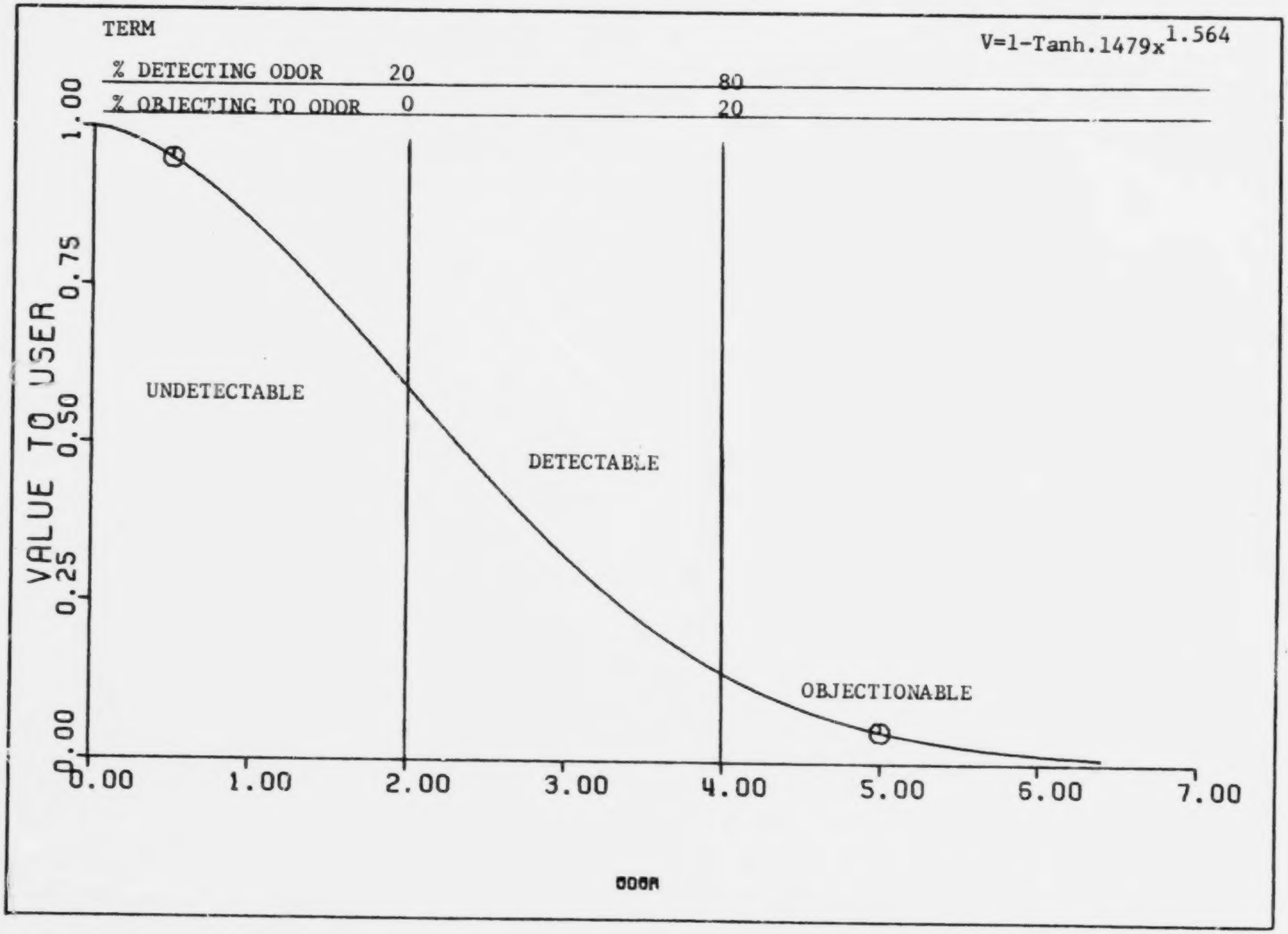
CURVE
1.4


FACTOR
V=1-Tanh187.5x^1.787
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
GRAMS/VEHICLE MILE
PARTICULATES

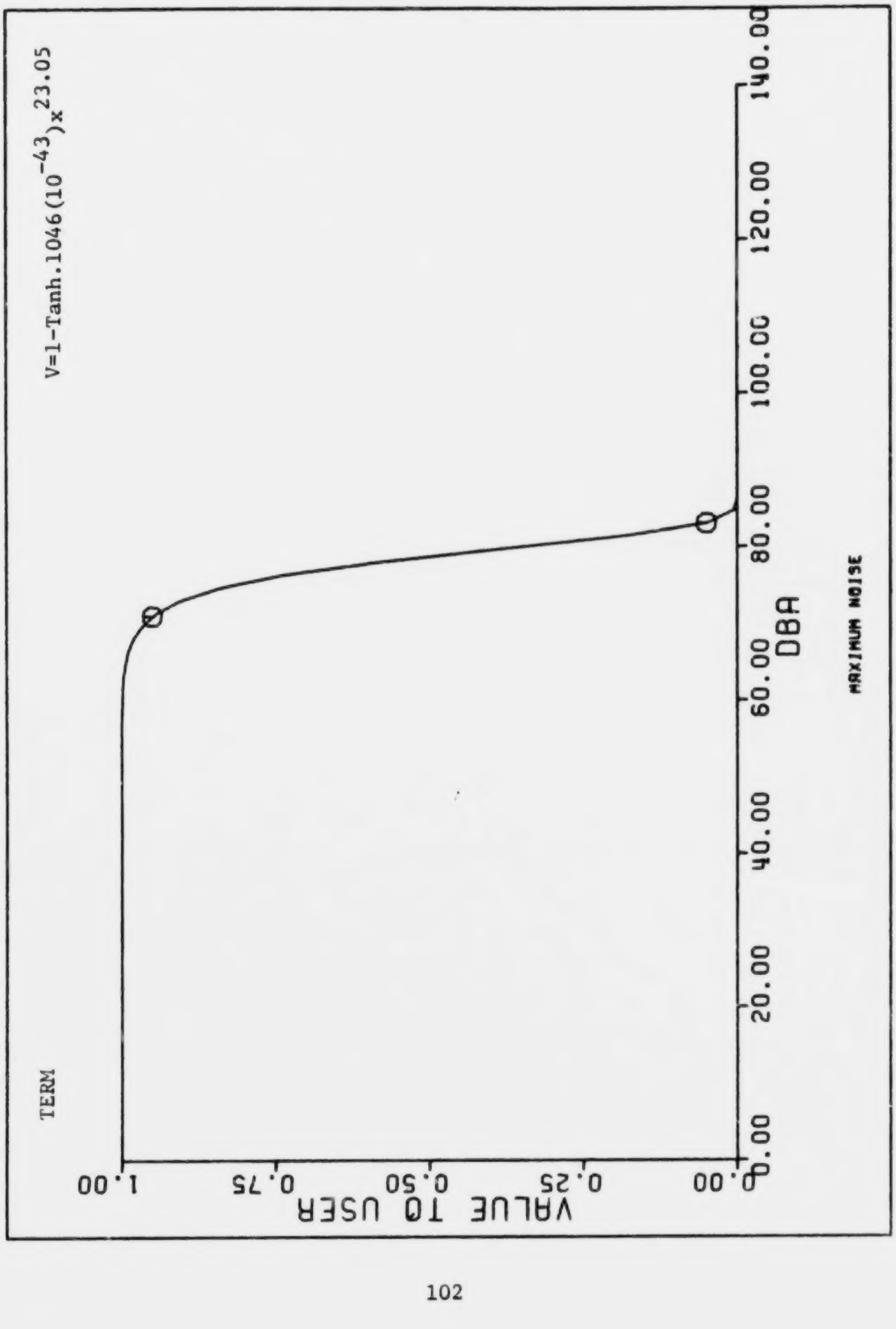
CURVE
1.5


TERM
V=1-Tanh.05004x^2.394
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
% OPACITY
SMOKE

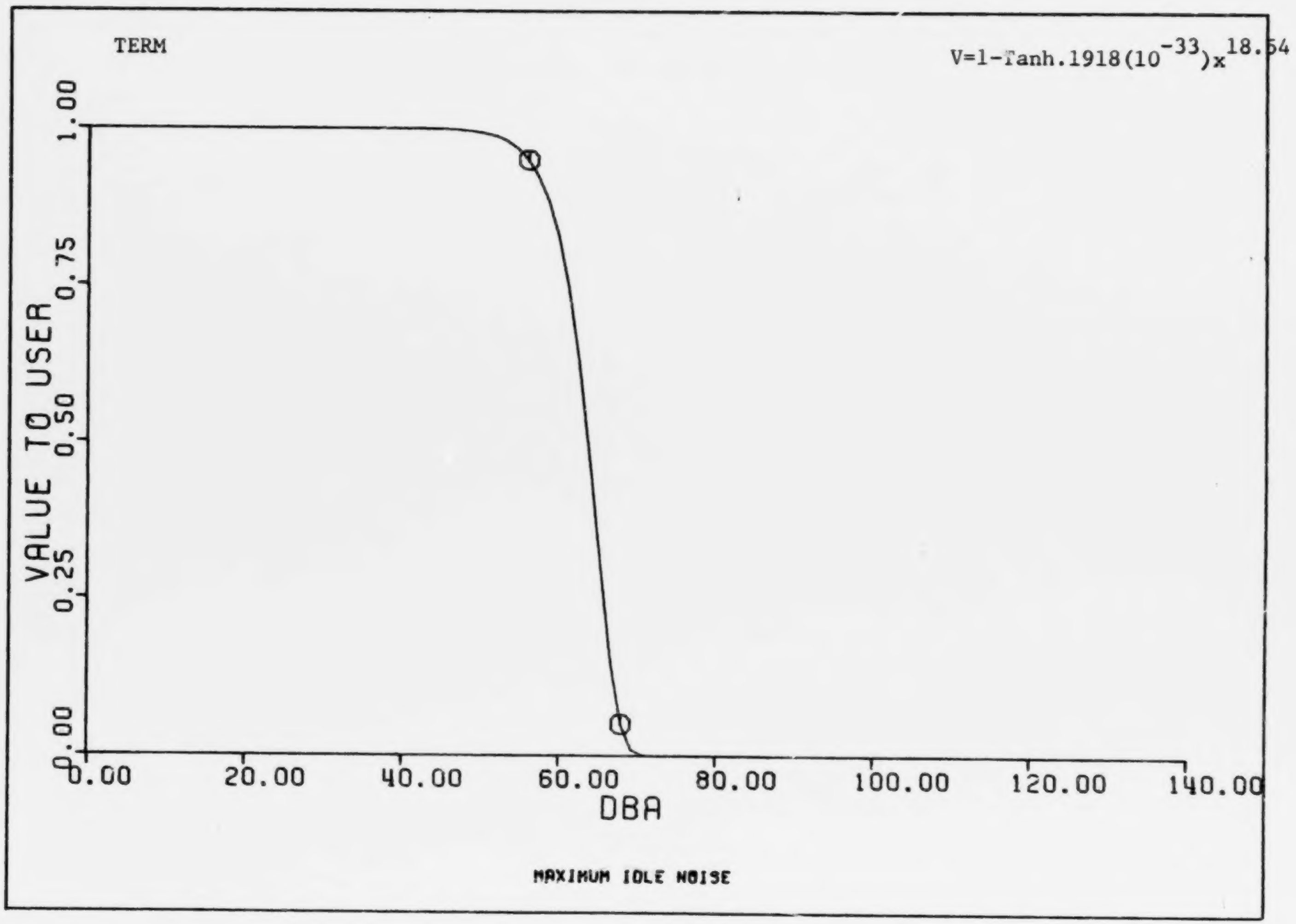
CURVE
1.6


TERM
% DETECTING ODOR 20 80
% OBJECTING TO ODOR 0 20
V=1-Tanh.1479x^1.564
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
UNDETECTABLE
DETECTABLE
OBJECTIONABLE
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
ODOR

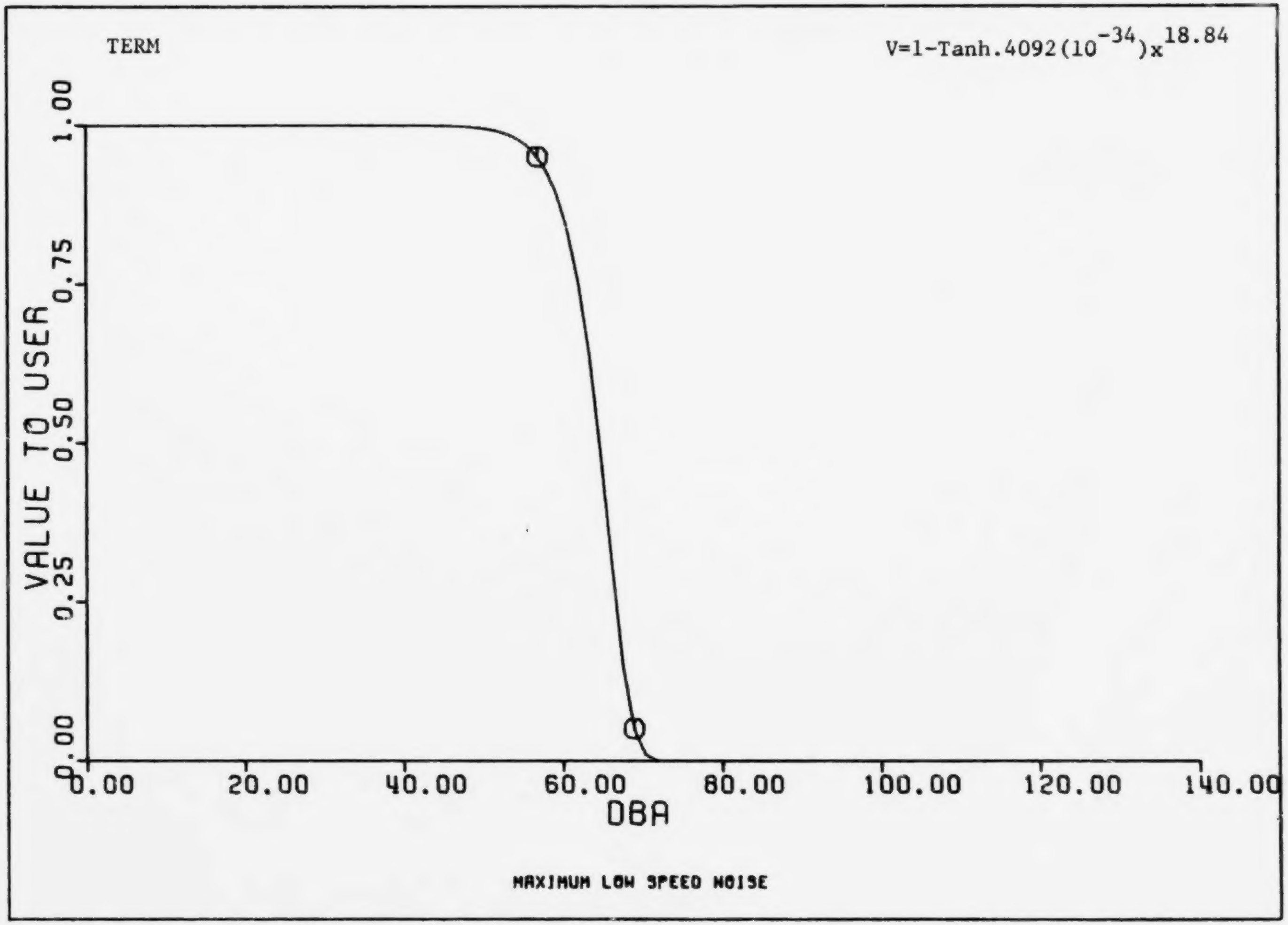
CURVE
1.7


V=1-Tanh.1046(10^-43)x^23.05
TERM
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
DBA
MAXIMUM NOISE

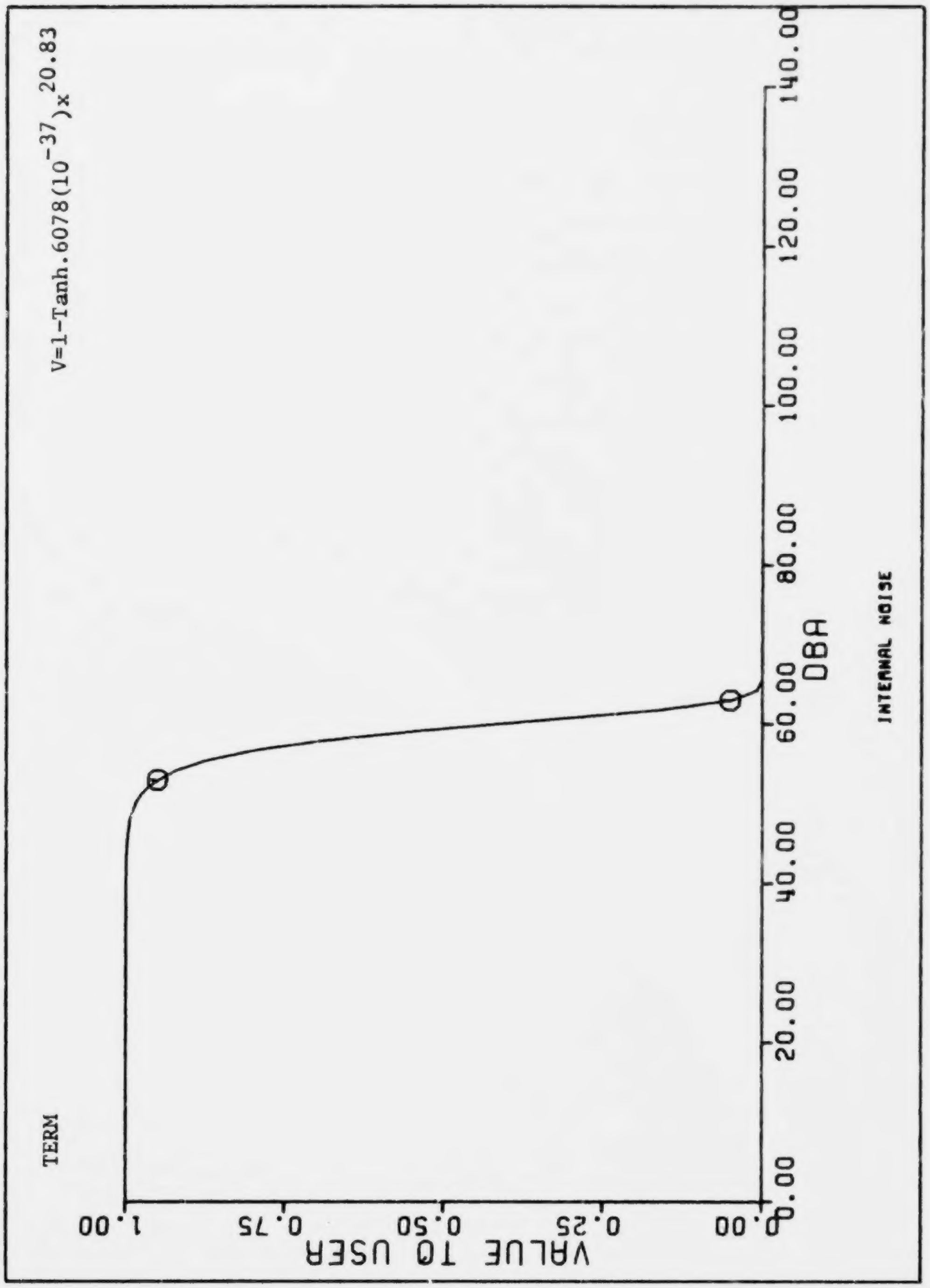
CURVE
1.8


TERM
$V=1-\text{Tanh}.1918(10^{-33})x^{18.54}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
DBA
MAXIMUM IDLE NOISE

CURVE
1.9


TERM
V=1-Tanh.4092(10^{-34})x$^{18.84}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
DBA
MAXIMUM LOW SPEED NOISE

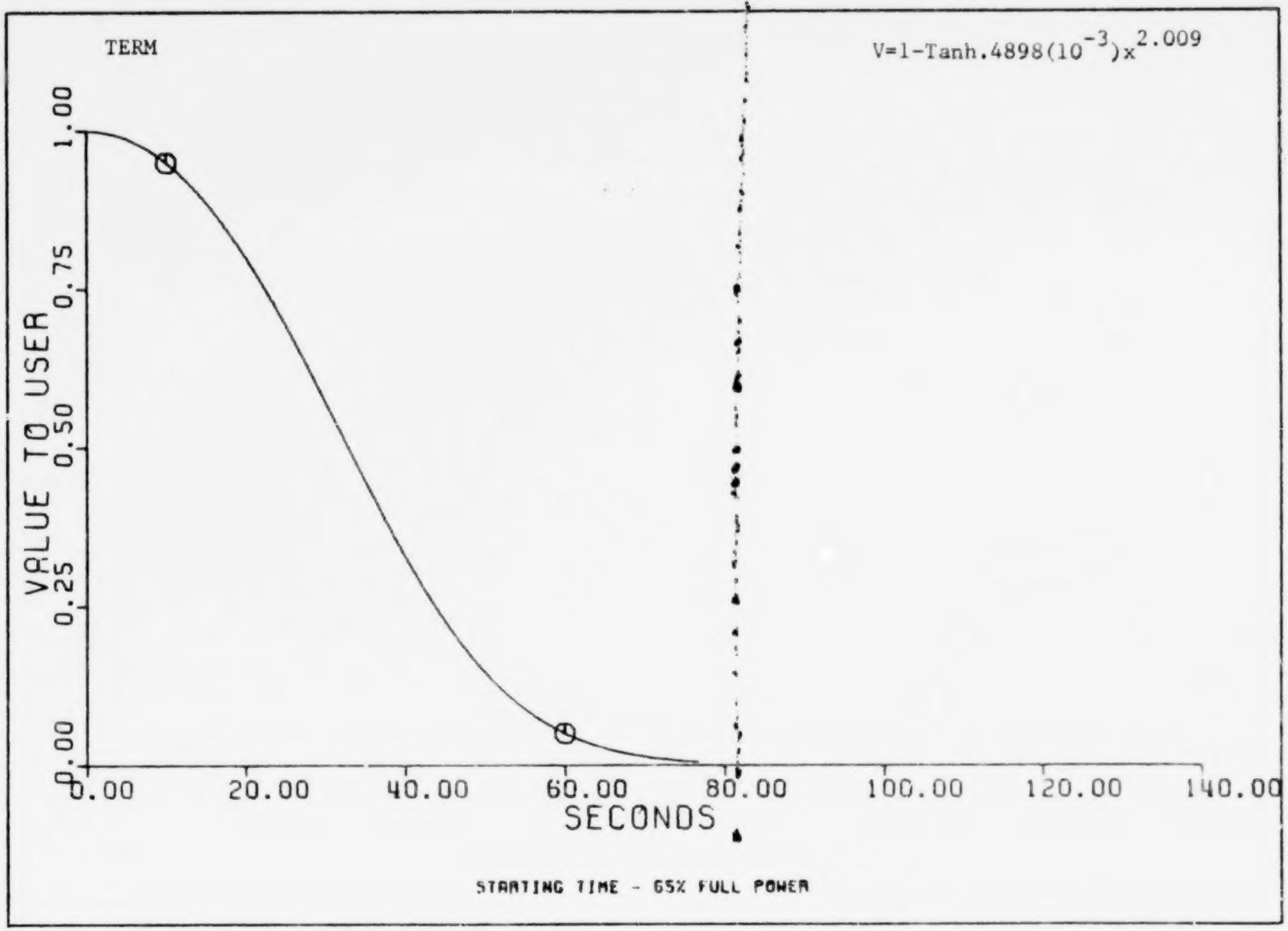
CURVE
1.10


TERM
$V=1-\tanh .6078(10^{-37})x^{20.83}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
DBA
INTERNAL NOISE

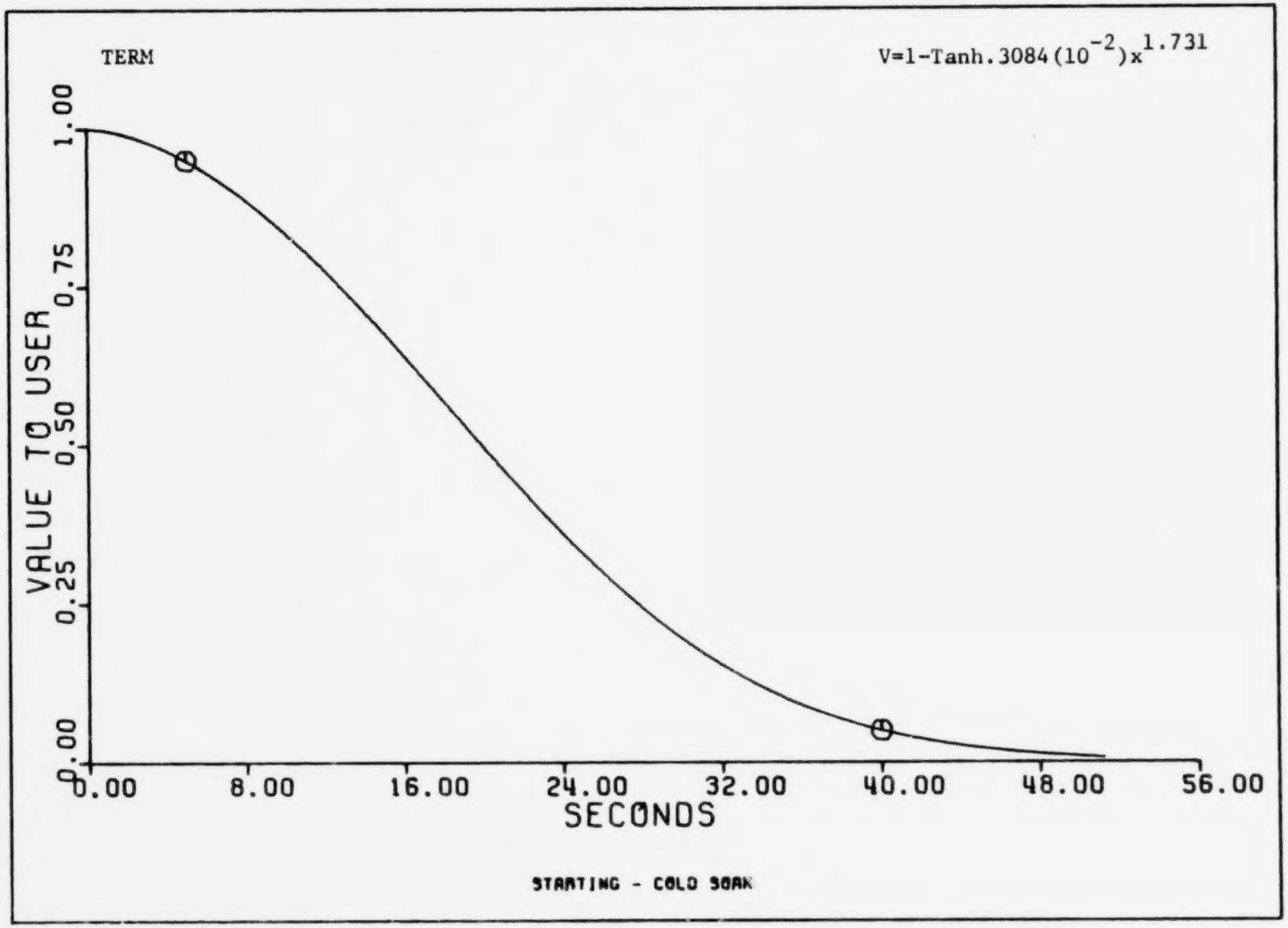
CURVE
1.11

4.1.3 Operating Performance Category

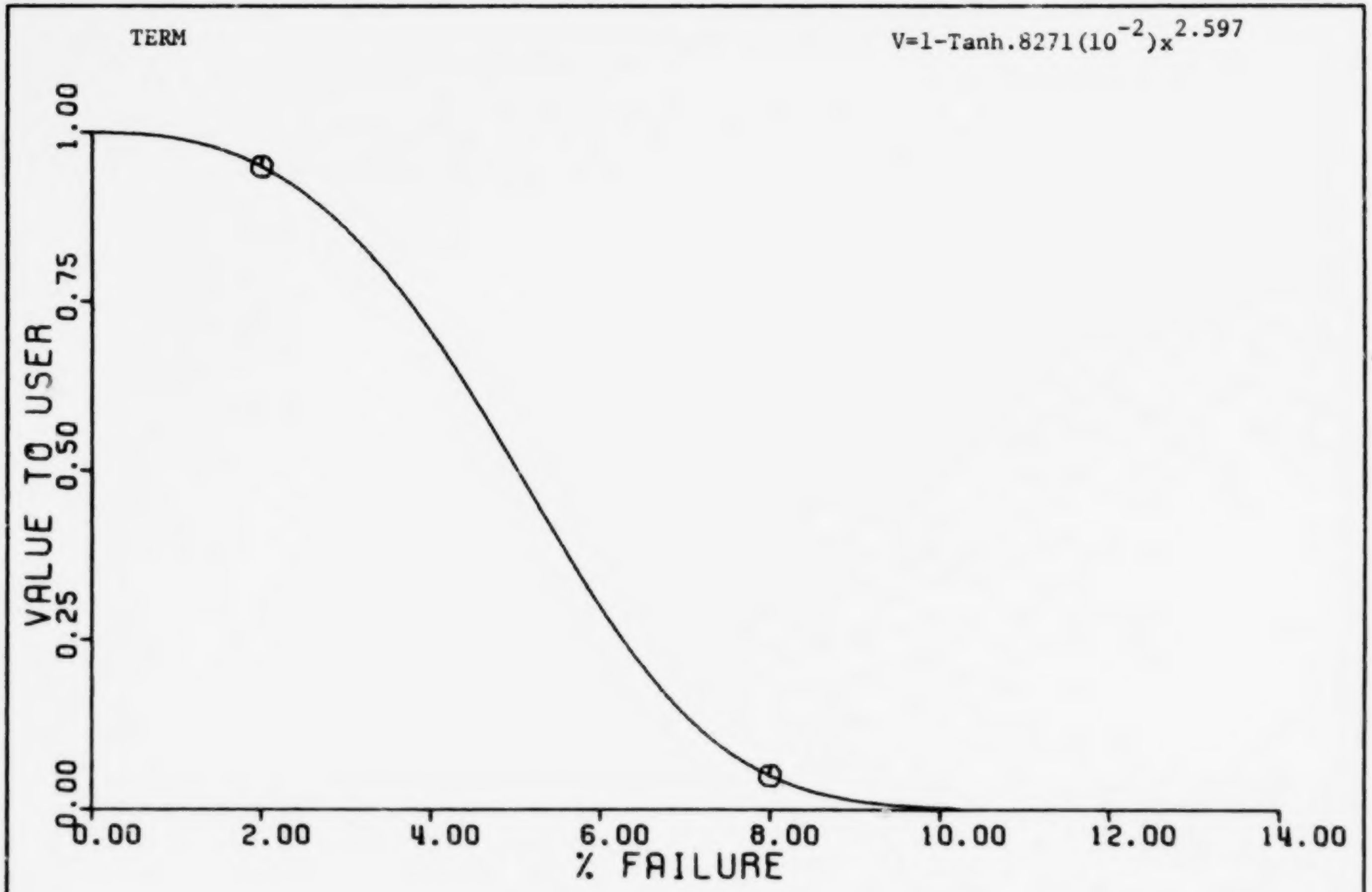
Starting Time - 65% Full Power - Curve 2.1
Starting - Cold Soak - Curve 2.2
Starting - Reliability - Curve 2.3
Idle Operations - Fuel Consumption - Curve 2.4
Idle Operations - Creep Torque - Curve 2.5
Idle Operations - Sustained - Curve 2.6
Acceleration - 10 Seconds - Curve 2.7
Acceleration - 25 - 70 MPH - Curve 2.8
DOT High Speed Pass - Curve 2.9
Cruise Speed - Curve 2.10
Maximum Speed - Curve 2.11
Grade Speed - Curve 2.12
Range - Cruise - Curve 2.13
Range - Urban - Curve 2.14

TERM
V=1-Tanh.4898(10^{-3})x$^{2.009}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
SECONDS
STARTING TIME - 65% FULL POWER

CURVE
2.1

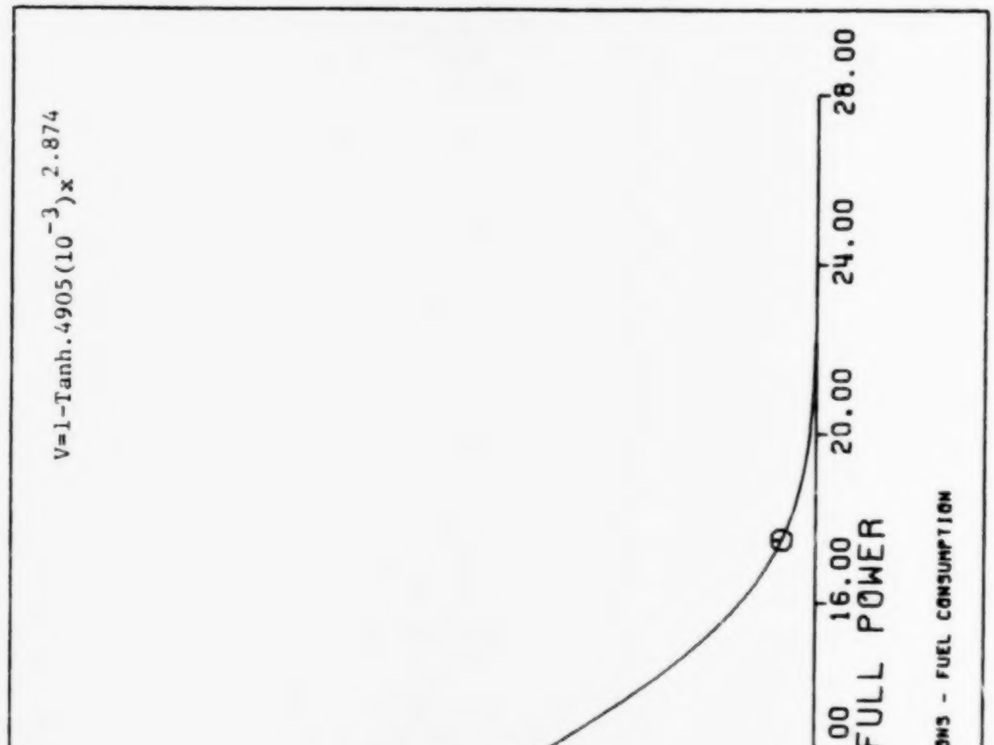

TERM
V=1-Tanh.3084(10^-2)x^1.731
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
SECONDS
STARTING - COLD SOAK

CURVE
2.2



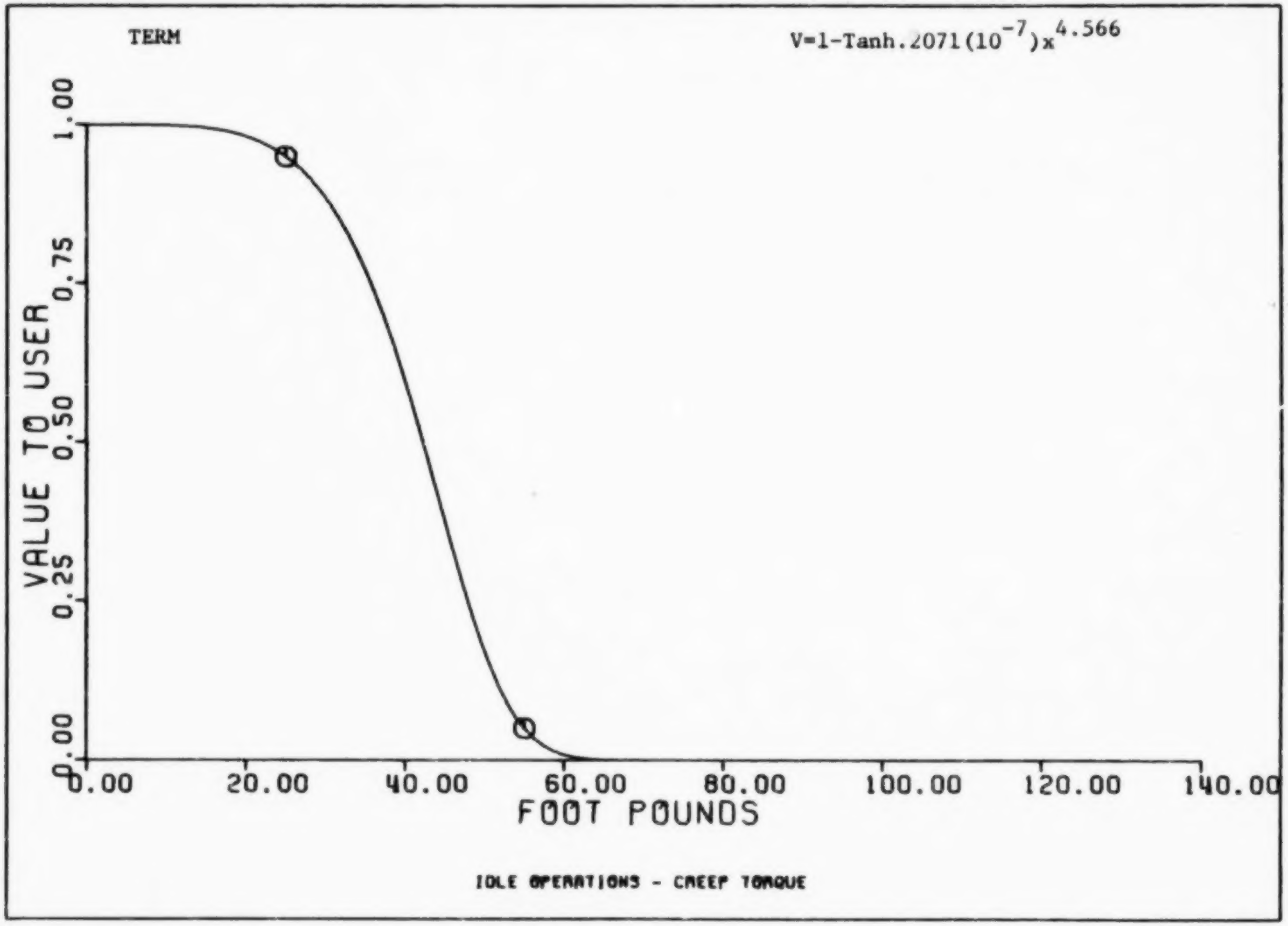
STARTING - RELIABILITY

CURVE
2.3

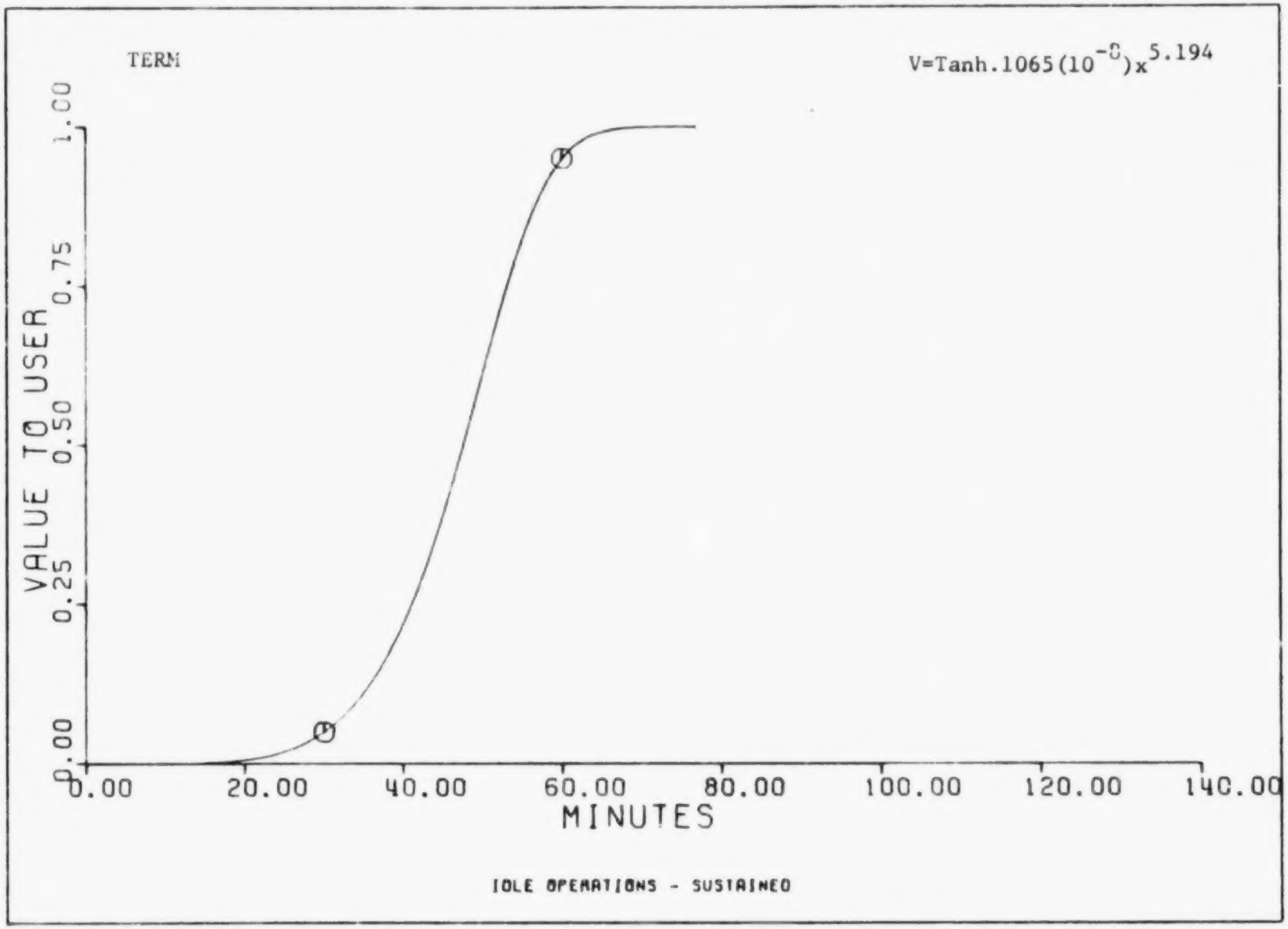


IDLE OPERATIONS - FUEL CONSUMPTION

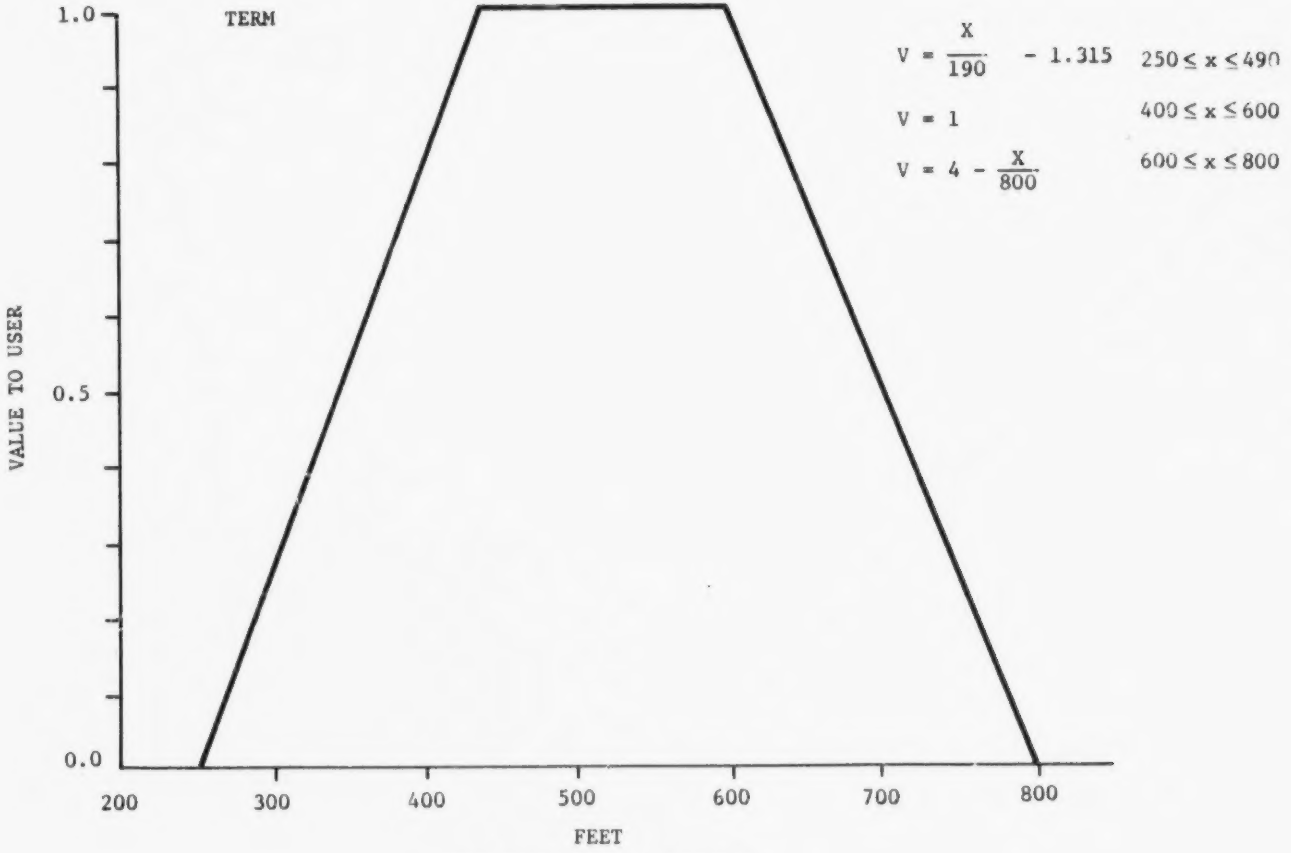
CURVE
2.4


TERM
V=1-Tanh.2071(10^-7)x^4.566
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
FOOT POUNDS
IDLE OPERATIONS - CREEP TORQUE

CURVE
2.5


TERM
V=Tanh.1065(10^-8)x^5.194
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
MINUTES
IDLE OPERATIONS - SUSTAINED

CURVE
2.6



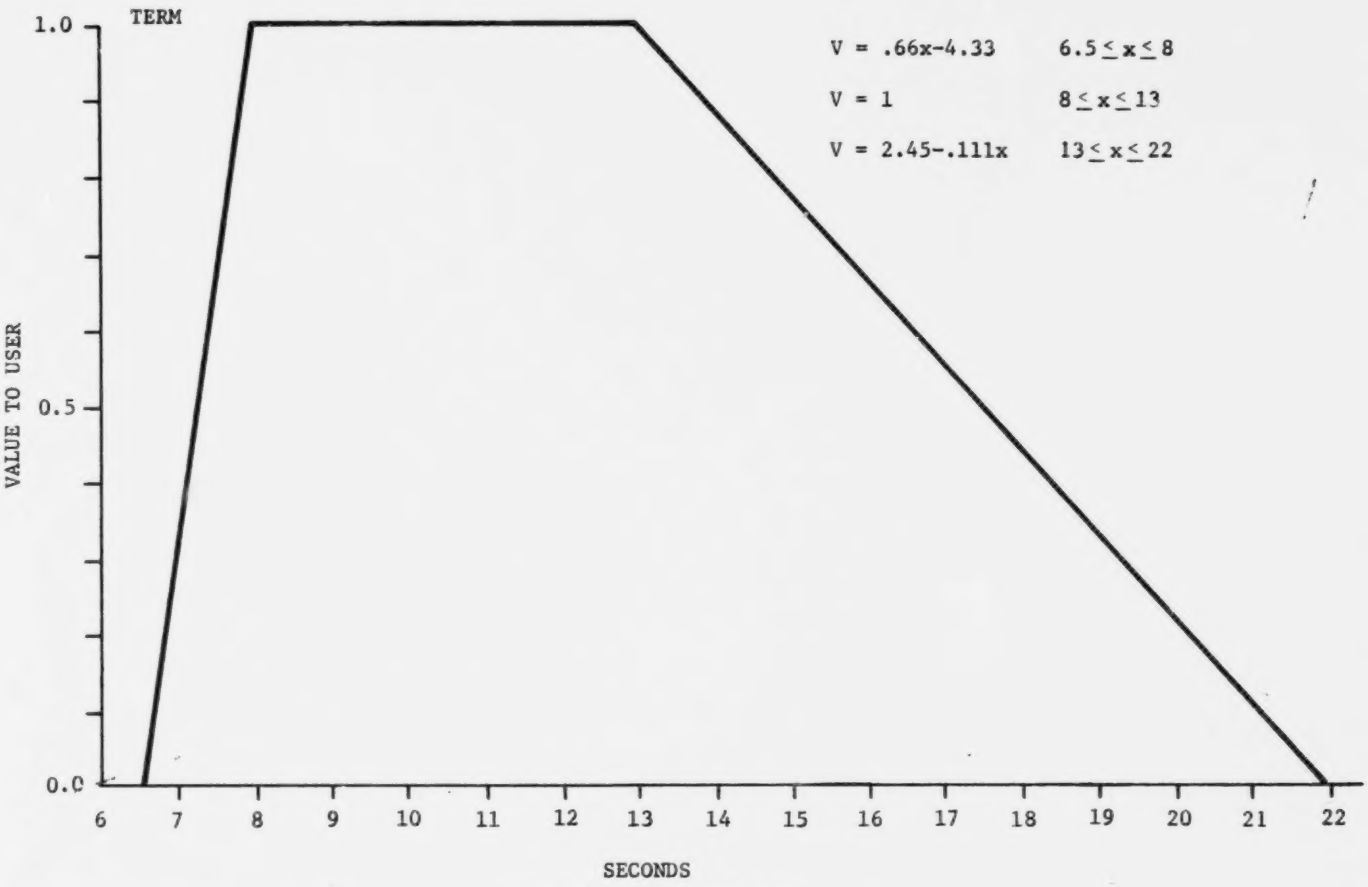
$V = \frac{X}{190} - 1.315 \qquad 250 \leq x \leq 490$

$V = 1 \qquad 400 \leq x \leq 600$

$V = 4 - \frac{X}{800} \qquad 600 \leq x \leq 800$

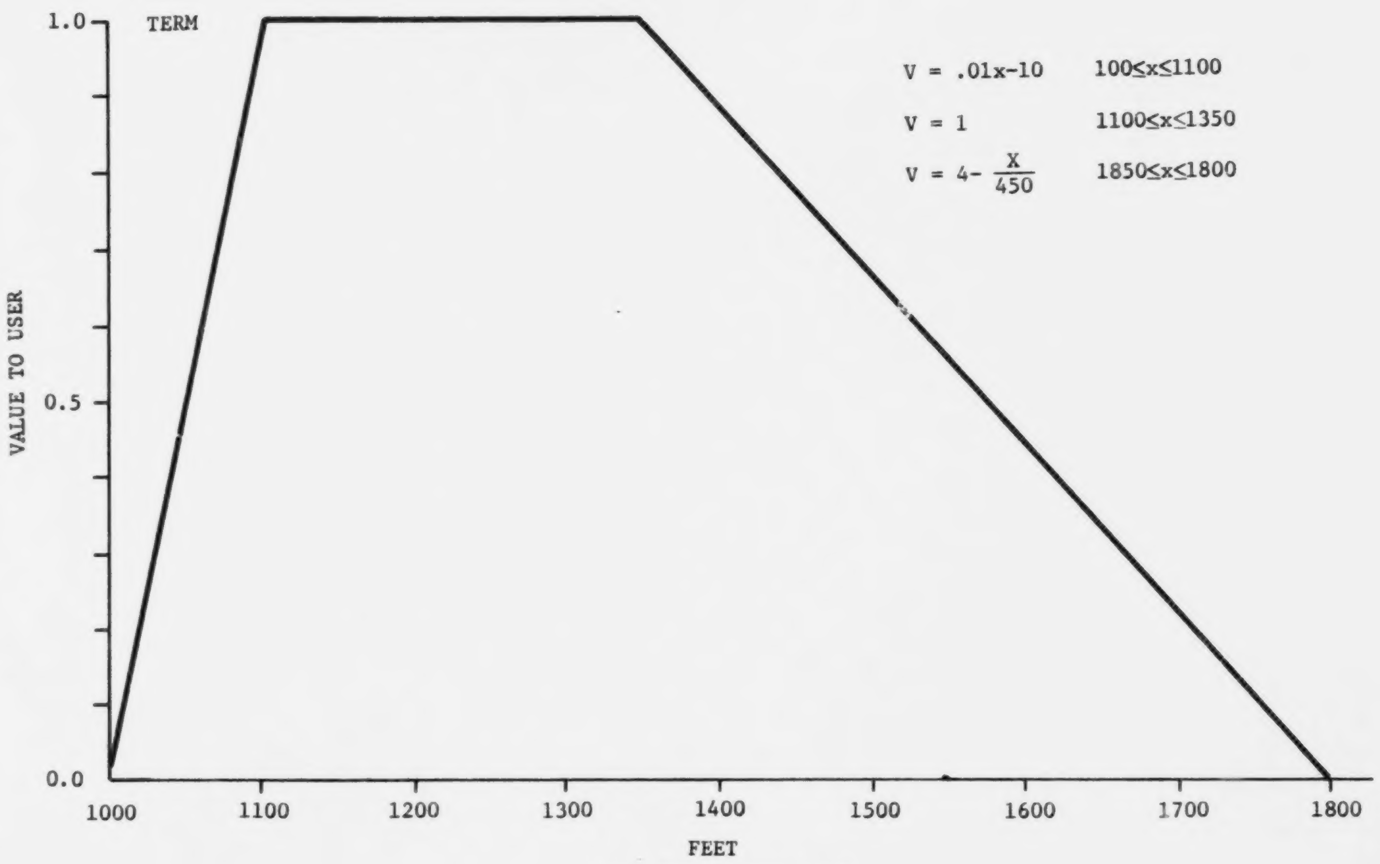
ACCELERATION - 10 SECONDS

CURVE
2.7



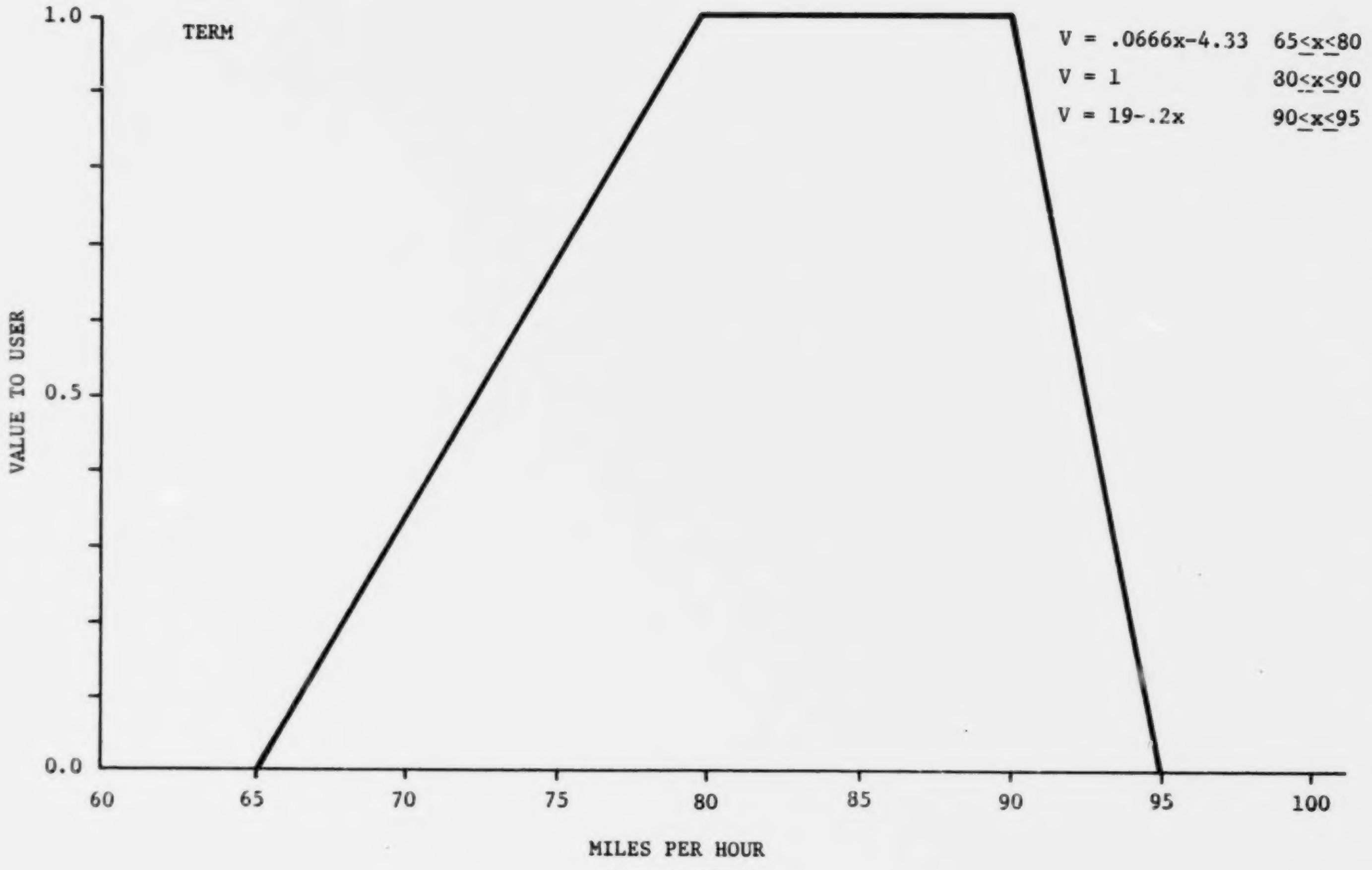
ACCELERATION 25-70 MPH

CURVE
2.8

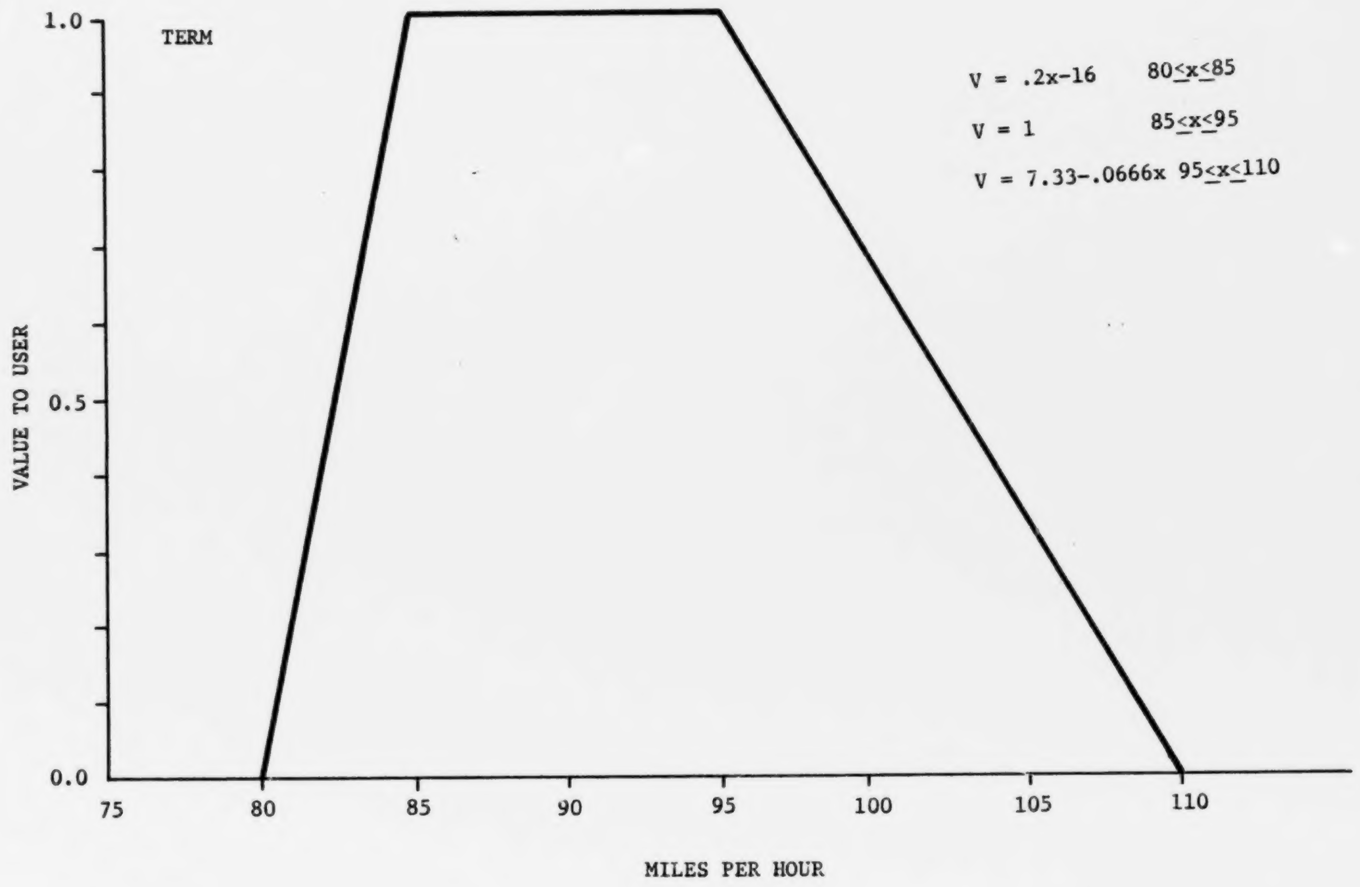


DOT HIGH SPEED PASS

CURVE
2.9

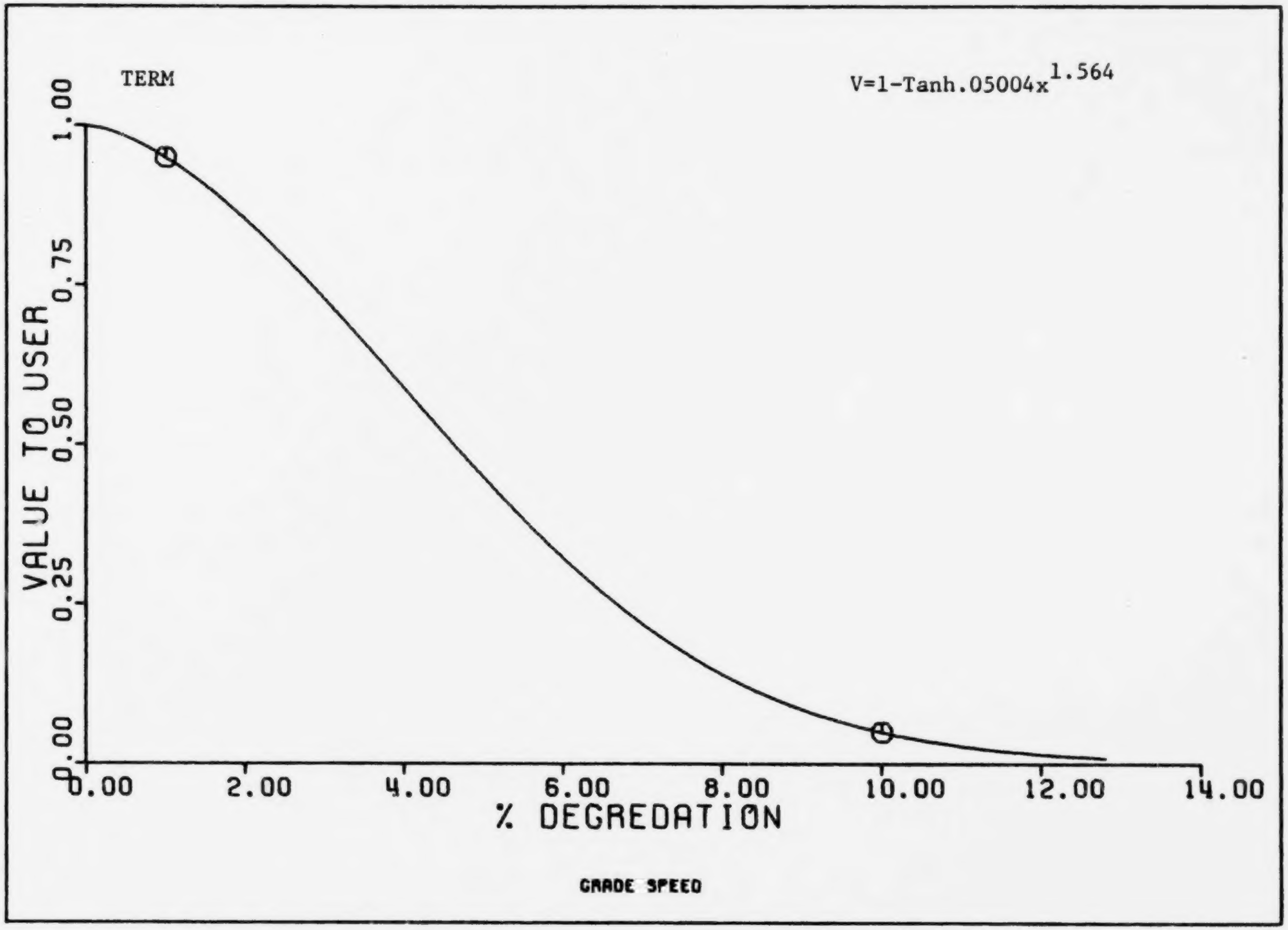

TERM
V = .0666x-4.33 $65 \leq x \leq 80$
V = 1 $30 \leq x \leq 90$
V = 19-.2x $90 \leq x \leq 95$
VALUE TO USER
1.0
0.5
0.0
60
65
70
75
80
85
90
95
100
MILES PER HOUR
CRUISE SPEED

CURVE
2.10

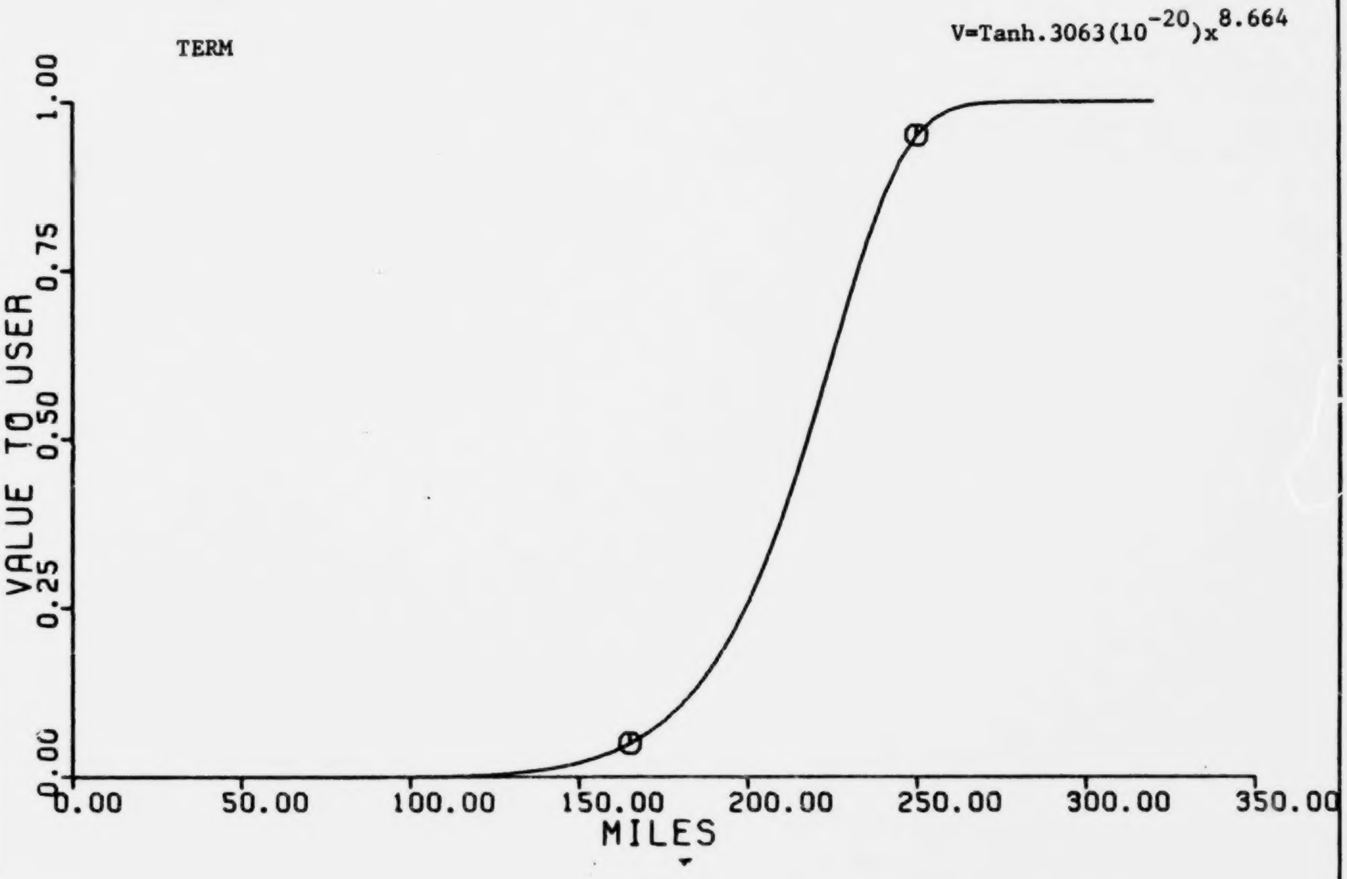


MAXIMUM SPEED

CURVE
2.11

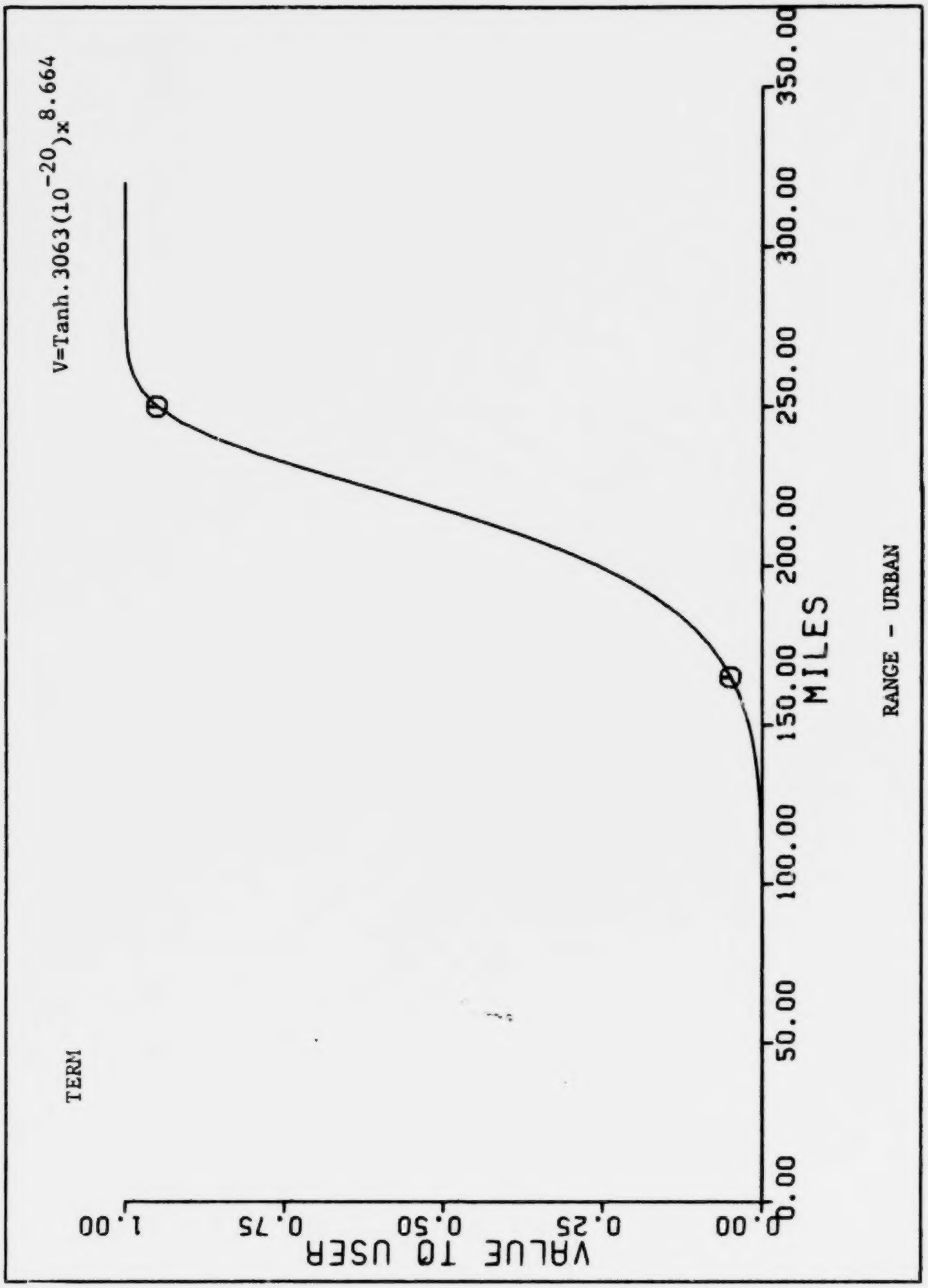

TERM
V=1-Tanh.05004x^1.564
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
% DEGREDATION
GRADE SPEED

CURVE
2.12



RANGE - CRUISE

CURVE
2.13

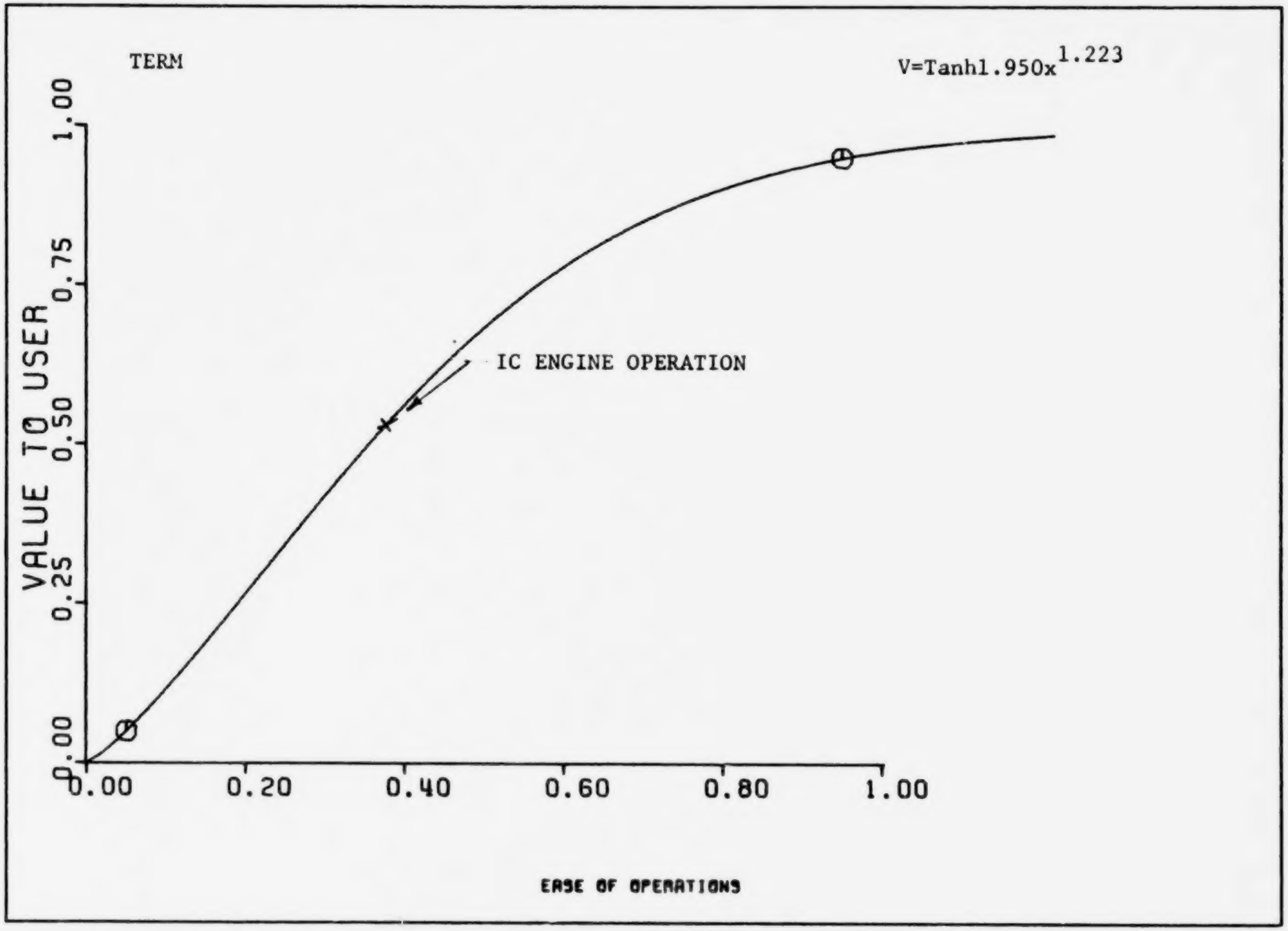


RANGE - URBAN

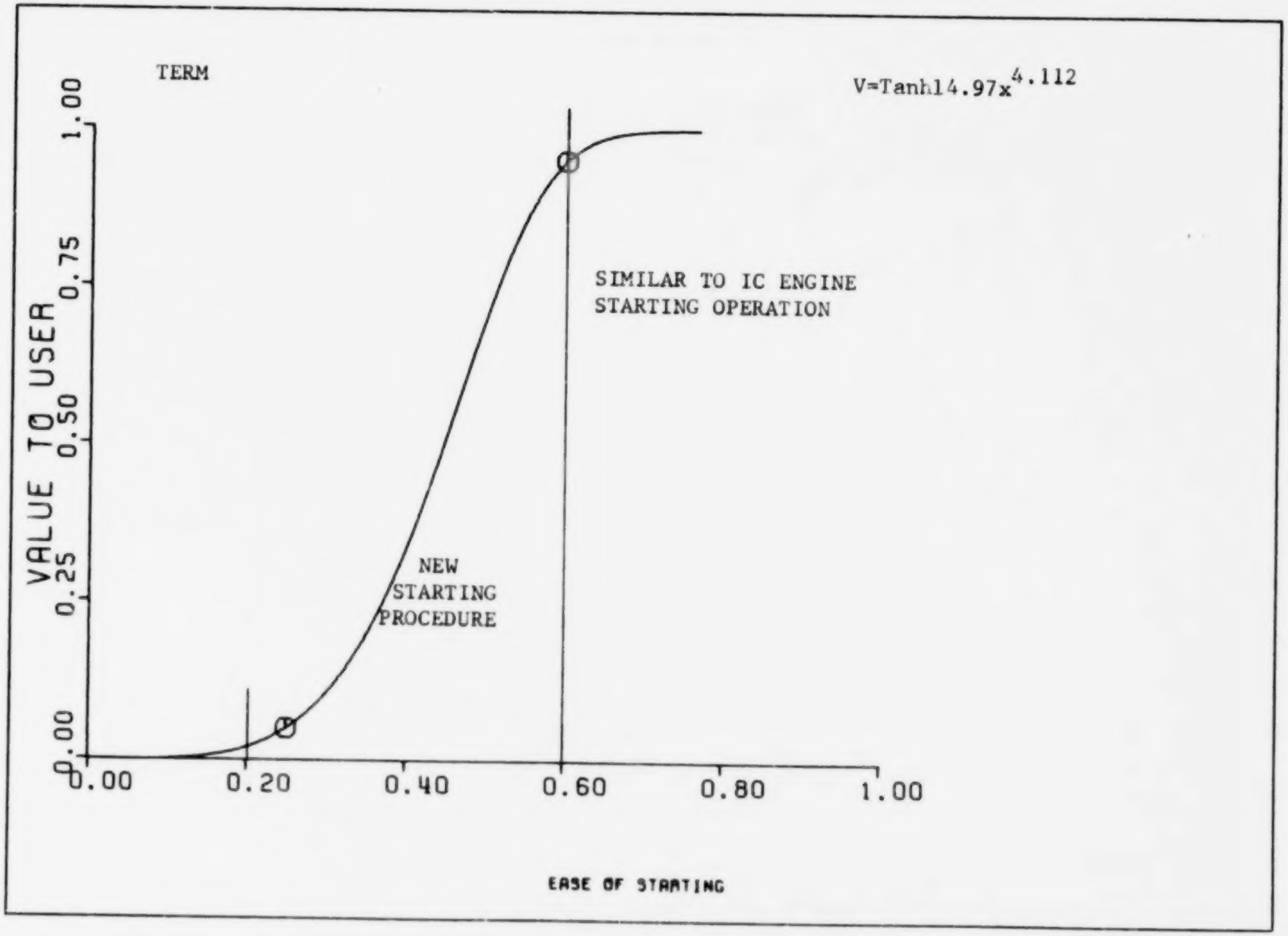
CURVE
2.14

4.1.4 Acceptability Category

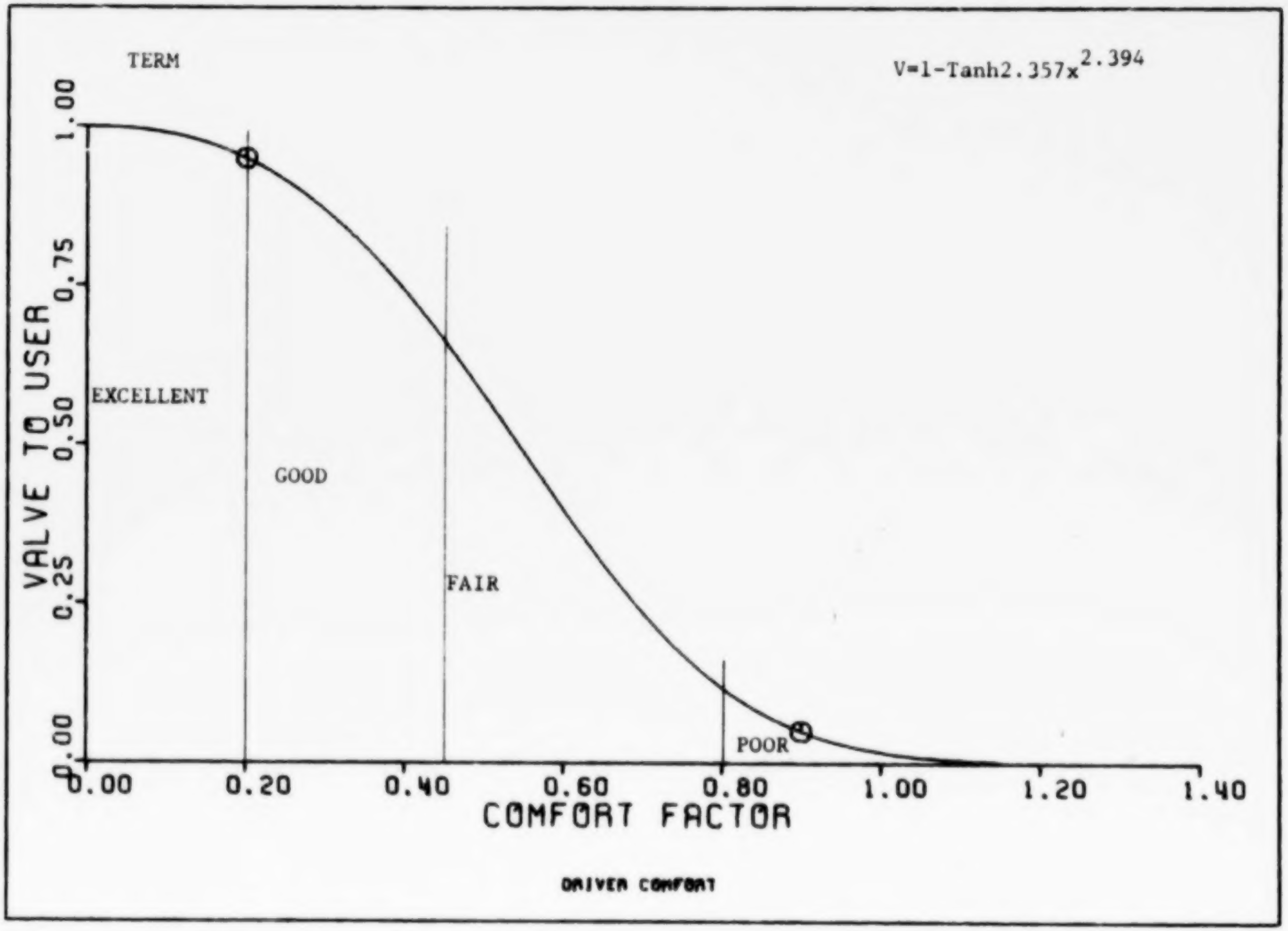
Ease of Operation - Curve 3.1
Ease of Starting - Curve 3.2
Driver Comfort - Curve 3.3
Versatility - Styling - Curve 3.4
Versatility - Minimum Size - Curve 3.5
Versatility - Maximum Size - Curve 3.6


TERM
V=Tanh1.950x$^{1.223}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
IC ENGINE OPERATION
0.00
0.20
0.40
0.60
0.80
1.00
EASE OF OPERATIONS

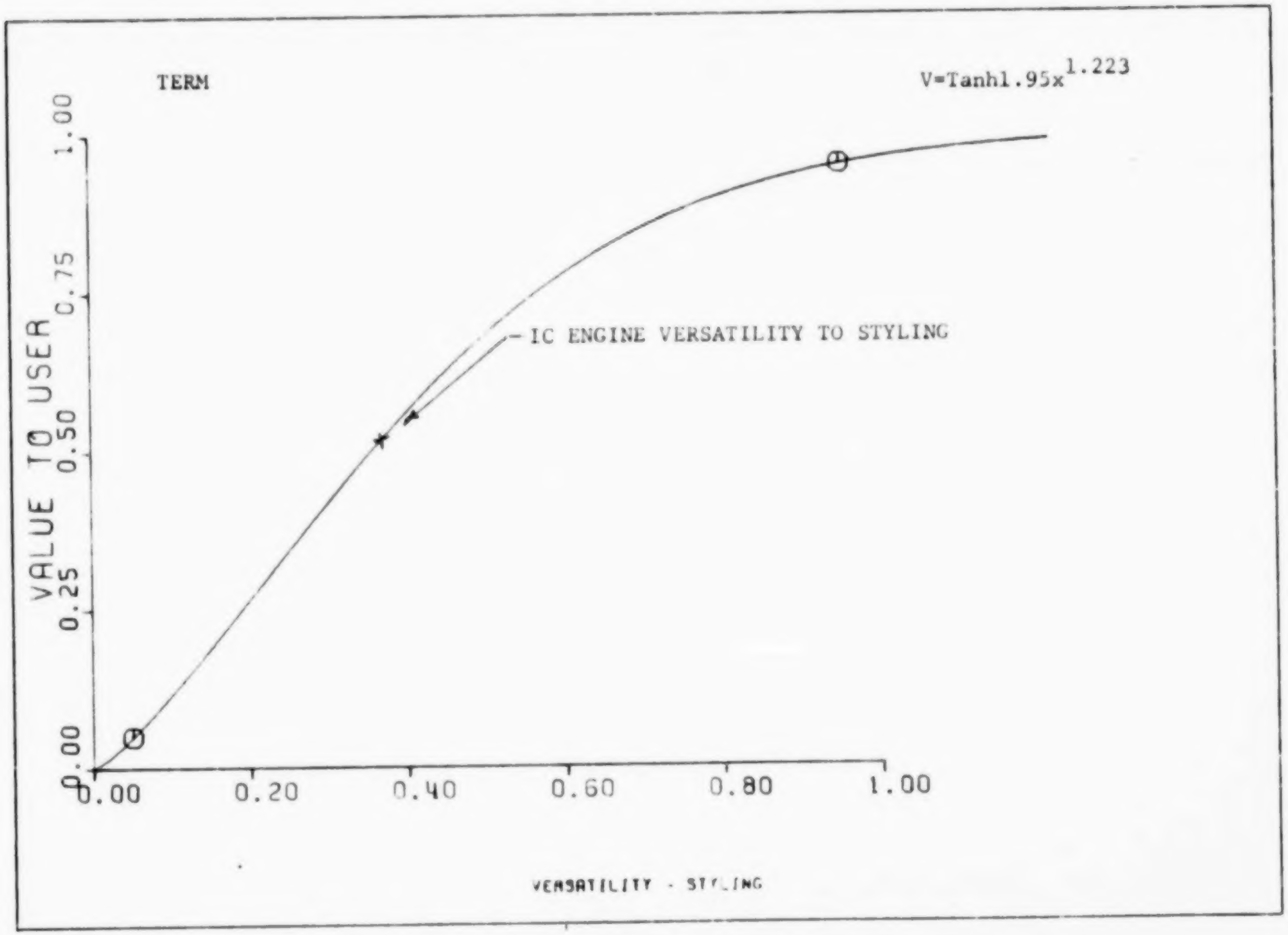
CURVE
3.1


TERM
V=Tanh14.97x^4.112
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
SIMILAR TO IC ENGINE
STARTING OPERATION
NEW
STARTING
PROCEDURE
0.00
0.20
0.40
0.60
0.80
1.00
EASE OF STARTING

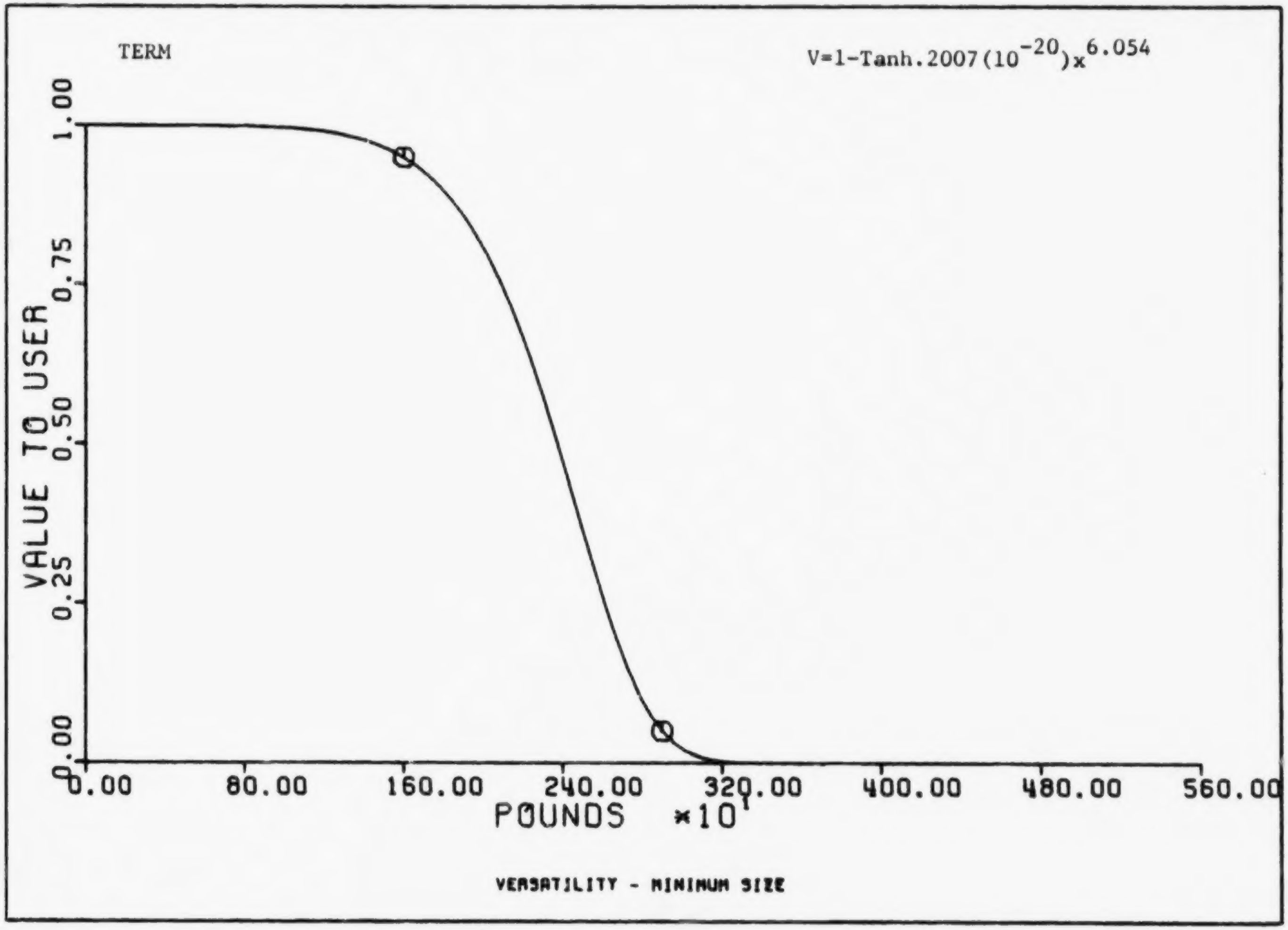
CURVE
3.2


TERM
V=1-Tanh2.357x^2.394
VALVE TO USER
1.00
0.75
0.50
0.25
0.00
EXCELLENT
GOOD
FAIR
POOR
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
COMFORT FACTOR
DRIVER COMFORT

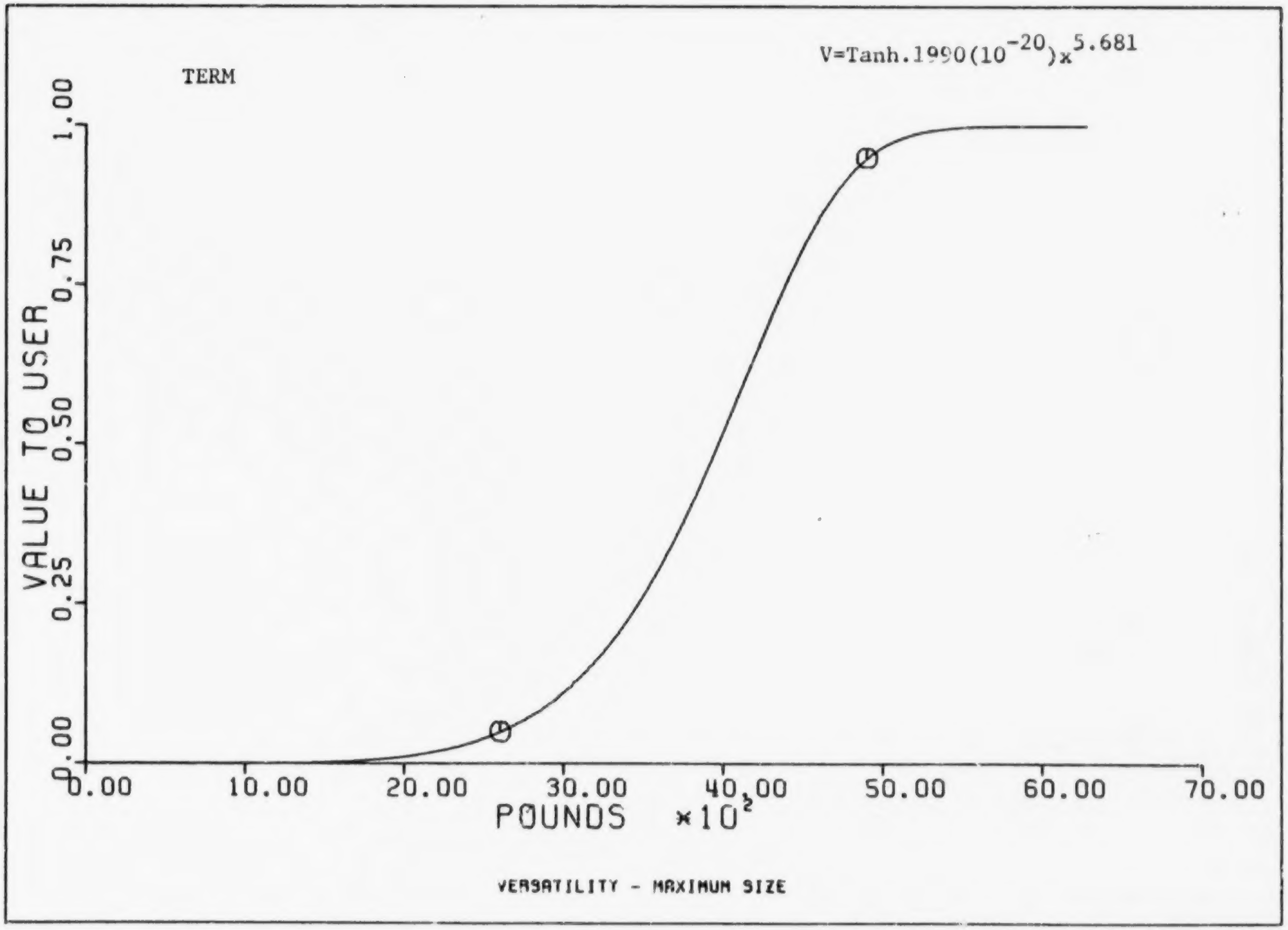
CURVE
3.3


TERM
V=Tanh1.95x^1.223
IC ENGINE VERSATILITY TO STYLING
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
VERSATILITY - STYLING

CURVE
3.4


TERM
V=1-Tanh.2007(10^-20)x^6.054
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
POUNDS *10^1
VERSATILITY - MINIMUM SIZE

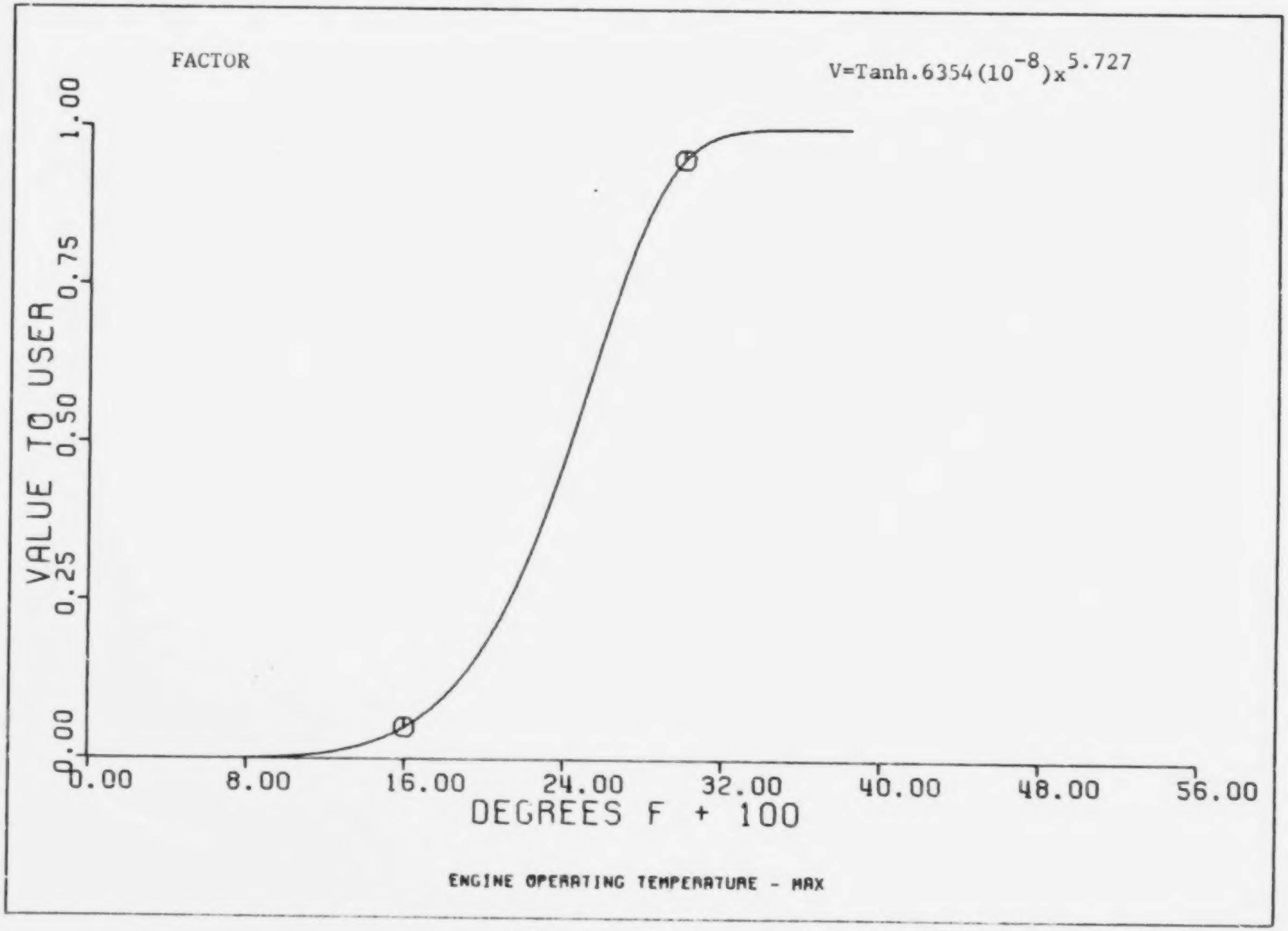
CURVE
3.5


TERM
V=Tanh.1990(10^-20)x^5.681
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
POUNDS ×10²
VERSATILITY - MAXIMUM SIZE

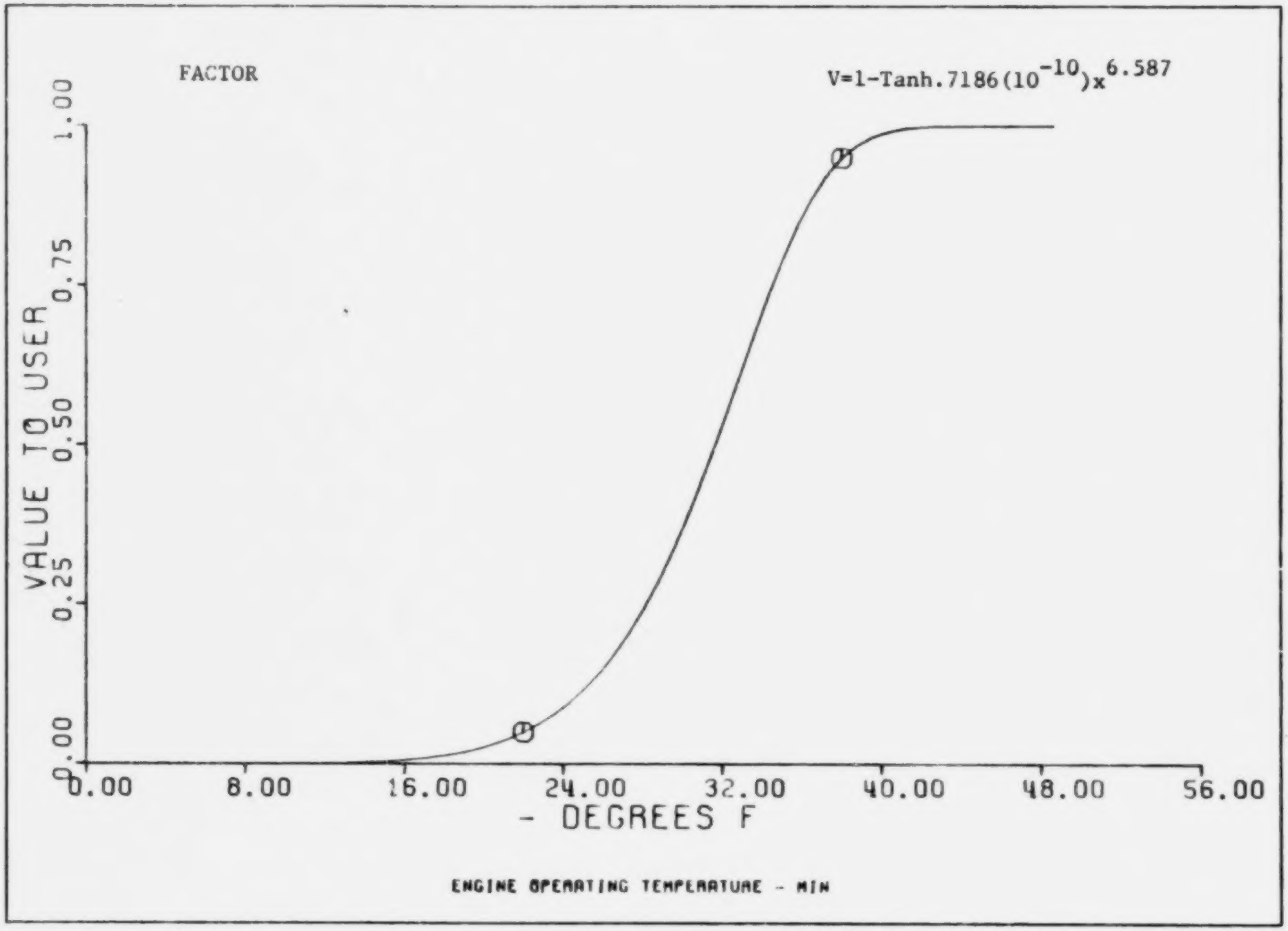
CURVE
3.6

4.1.5 Operating Environment Category

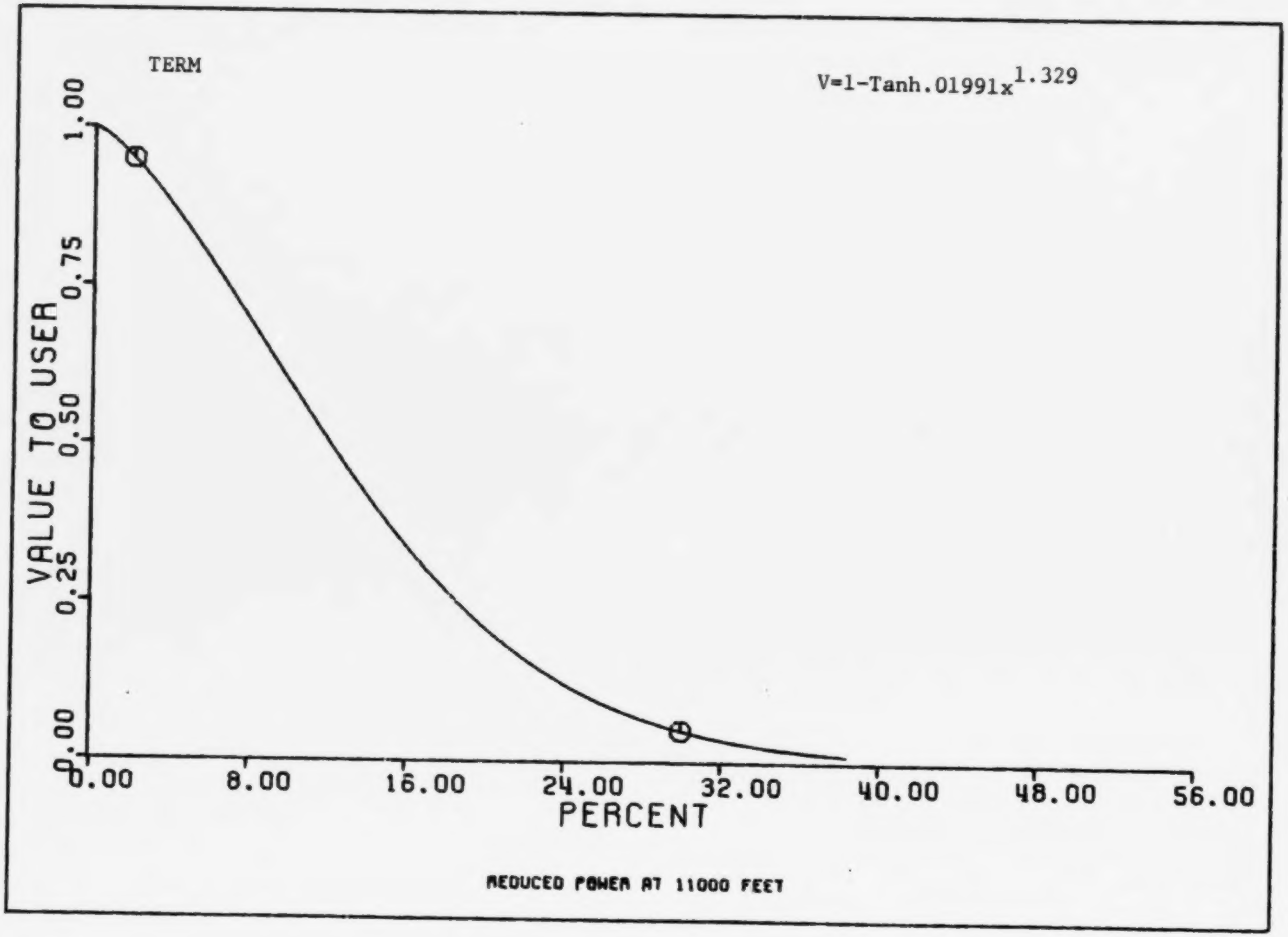
Engine Operating Temperature - Max - Curve 4.1
Engine Operating Temperature - Min - Curve 4.2
Reduced Power at 11000 feet - Curve 4.3
Reduced Power Due to Adverse Weather - Curve 4.4
Reduced Power - 40 MPH Wind - Curve 4.5
Reduced Power - 75 MPH Wind - Curve 4.6
Operability in Dust or Sand - Curve 4.7


FACTOR
V=Tanh.6354(10^-8)x^5.727
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
DEGREES F + 100
ENGINE OPERATING TEMPERATURE - MAX

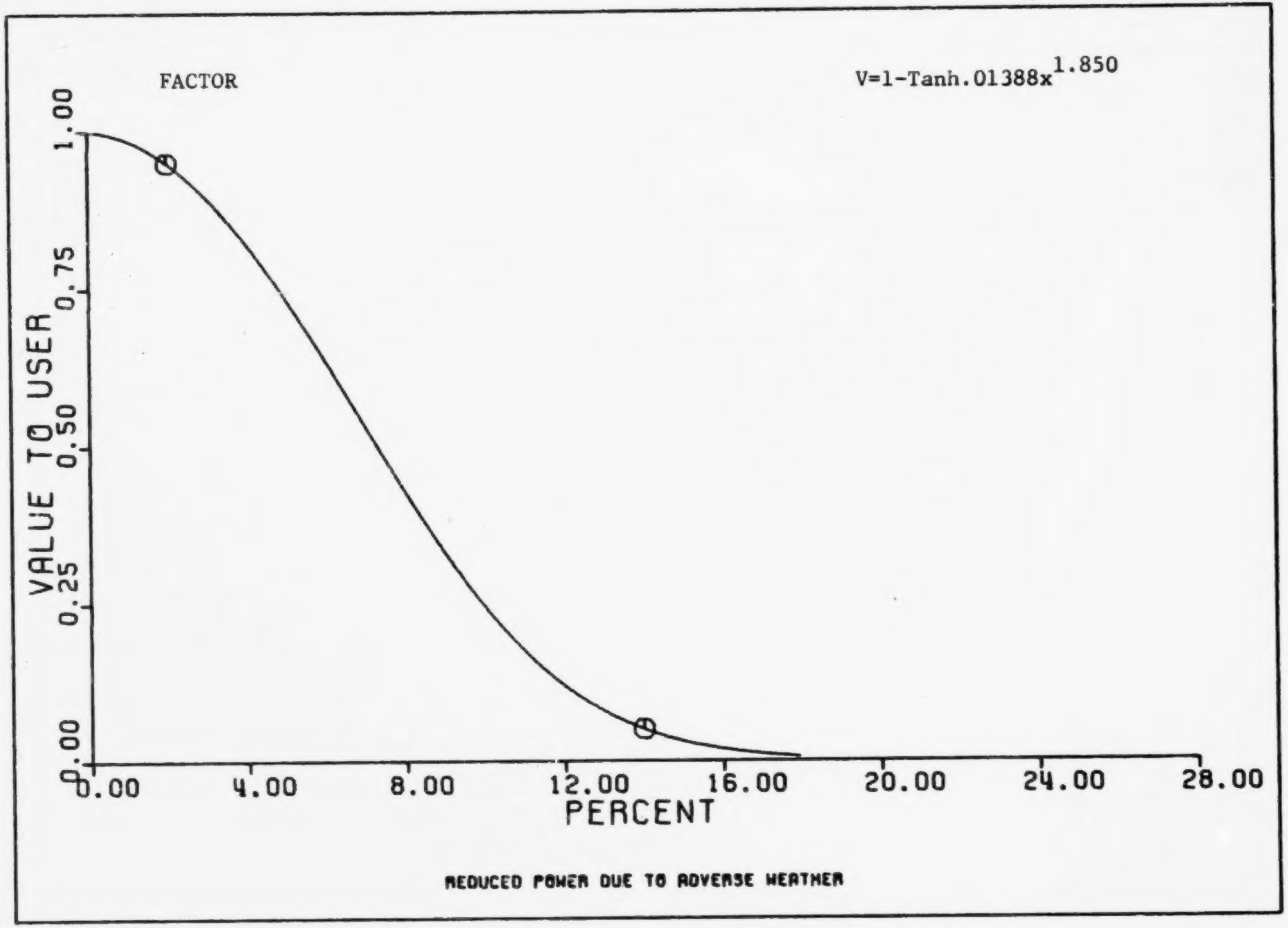
CURVE
4.1


FACTOR
V=1-Tanh.7186(10^-10)x^6.587
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
- DEGREES F
ENGINE OPERATING TEMPERATURE - MIN

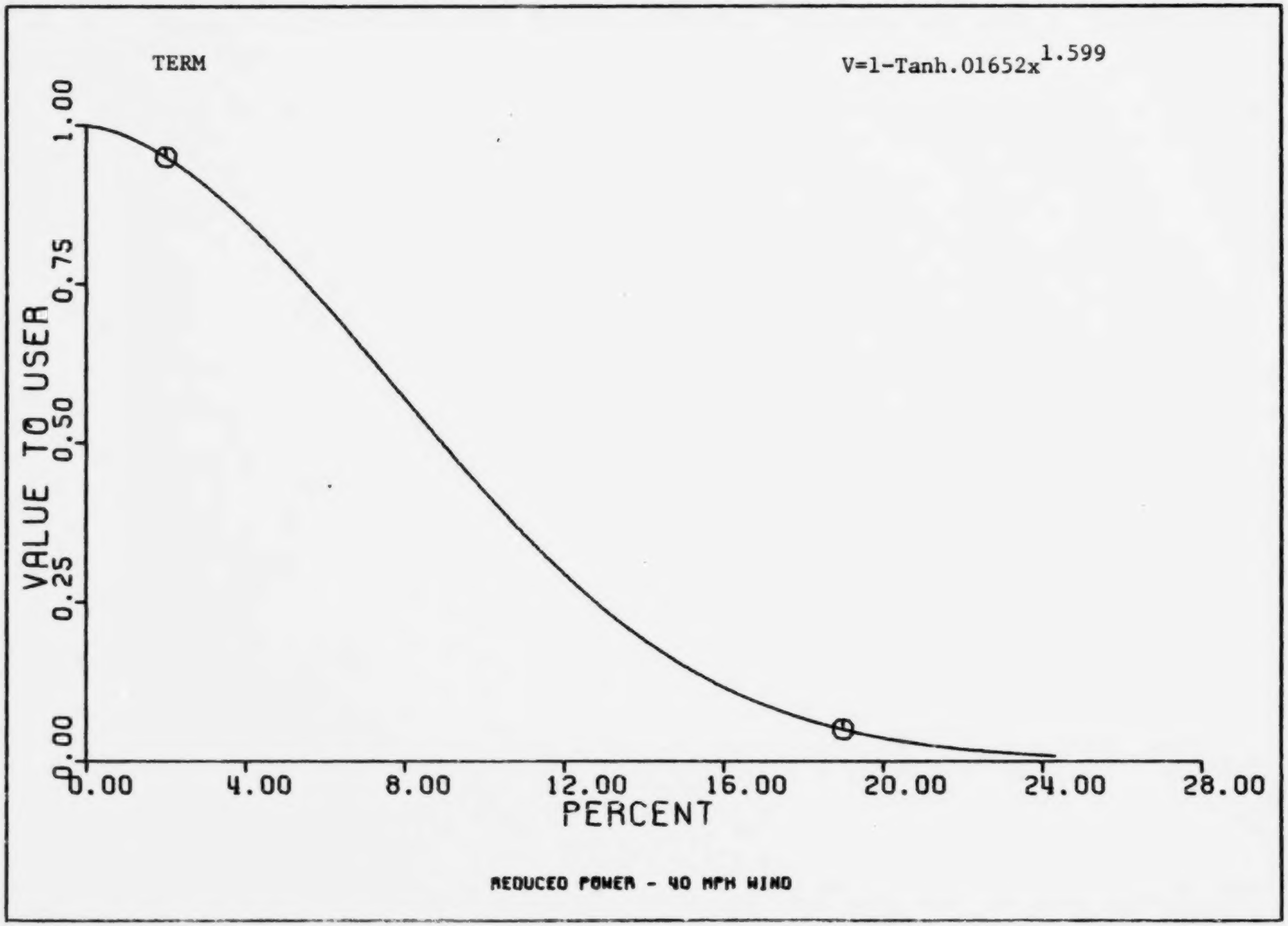
CURVE
4.2


TERM
V=1-Tanh.01991x^1.329
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
PERCENT
REDUCED POWER AT 11000 FEET

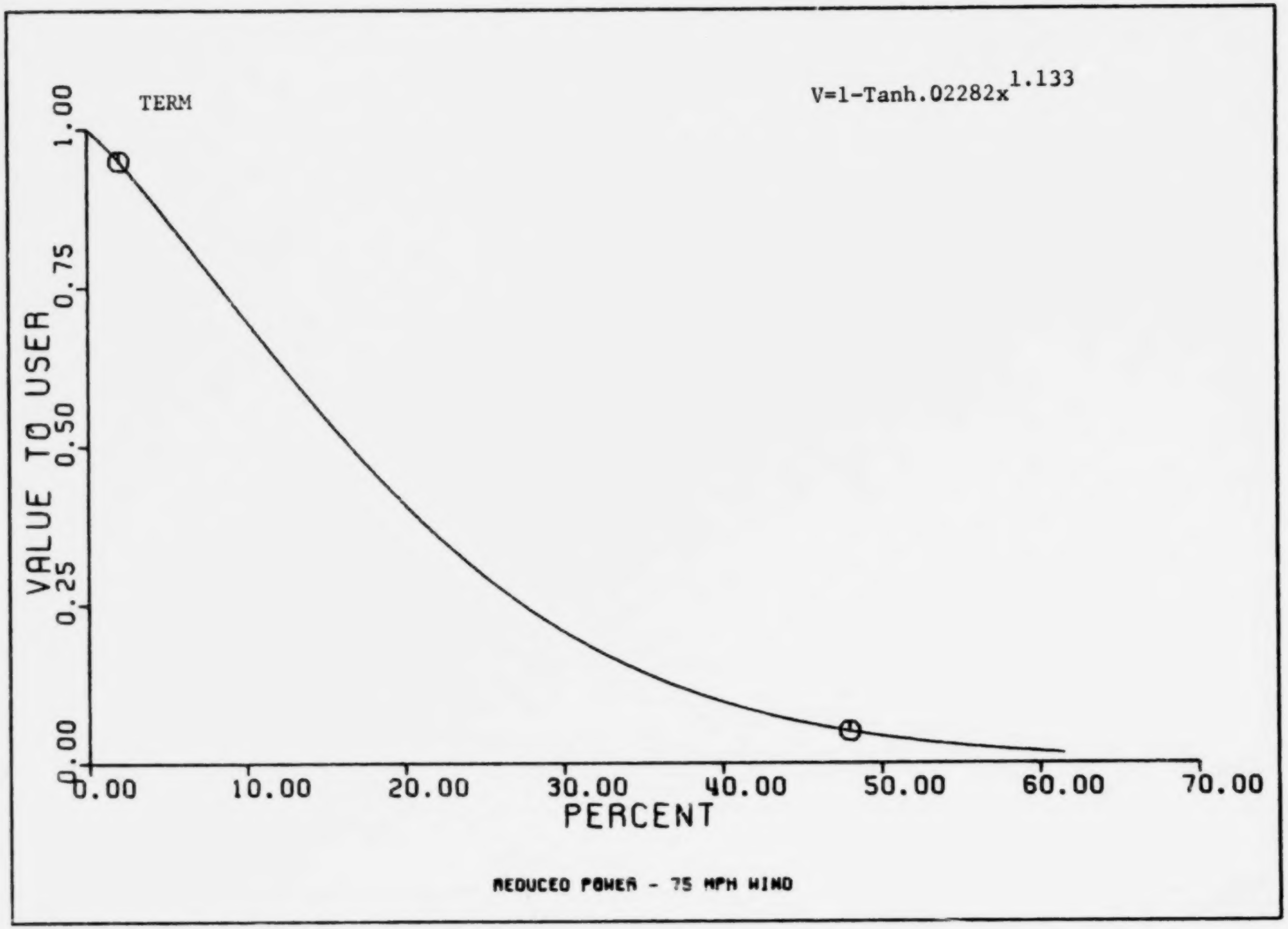
CURVE
4.3


FACTOR
V=1-Tanh.01388x^1.850
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
PERCENT
REDUCED POWER DUE TO ADVERSE WEATHER

CURVE
4.4

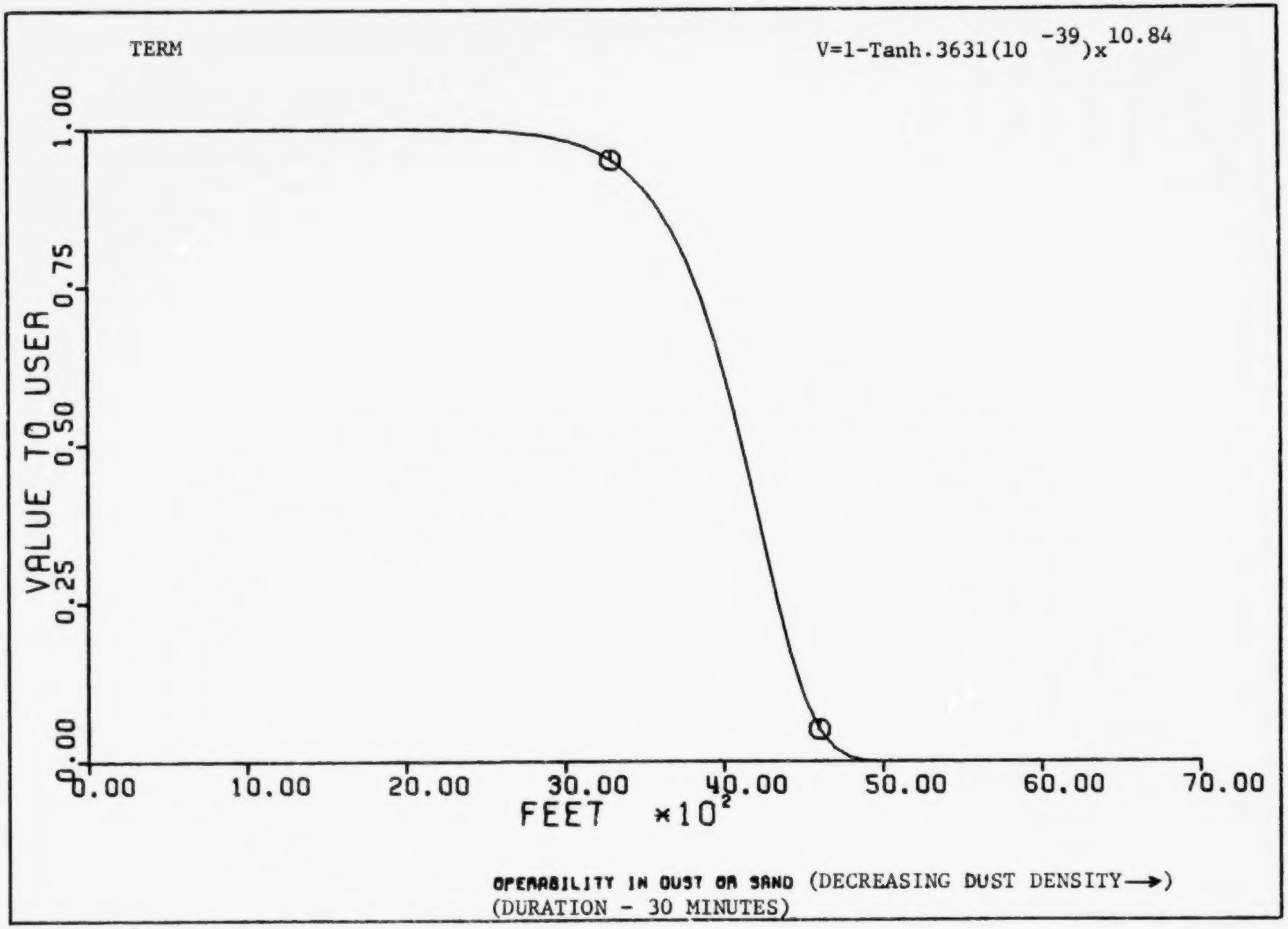

TERM
V=1-Tanh.01652x$^{1.599}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
PERCENT
REDUCED POWER - 40 MPH WIND

CURVE
4.5



REDUCED POWER - 75 MPH WIND

CURVE
4.6

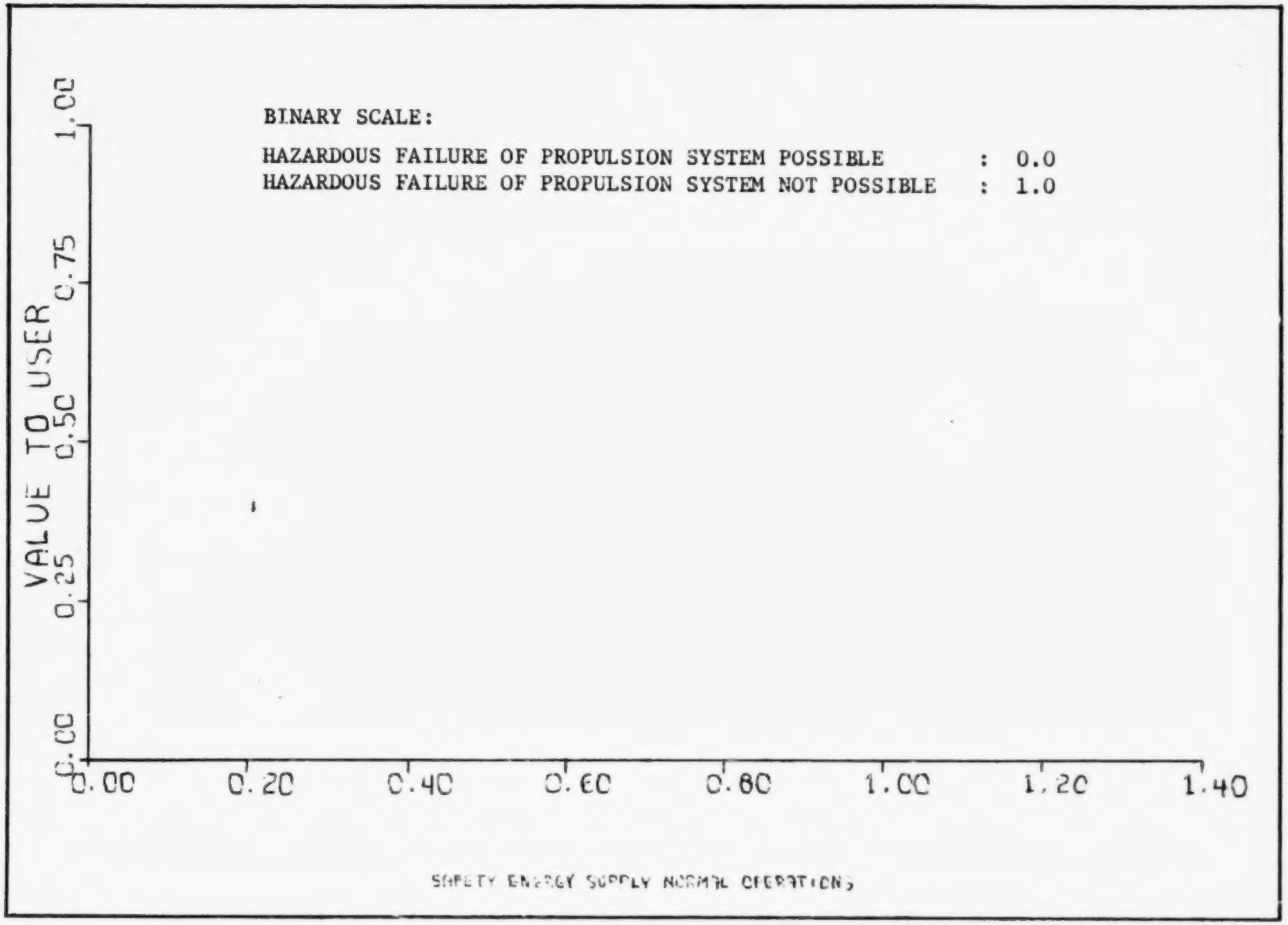


OPERABILITY IN DUST OR SAND (DECREASING DUST DENSITY ⟶)
(DURATION - 30 MINUTES)

CURVE
4.7

4.1.6 Safety Category

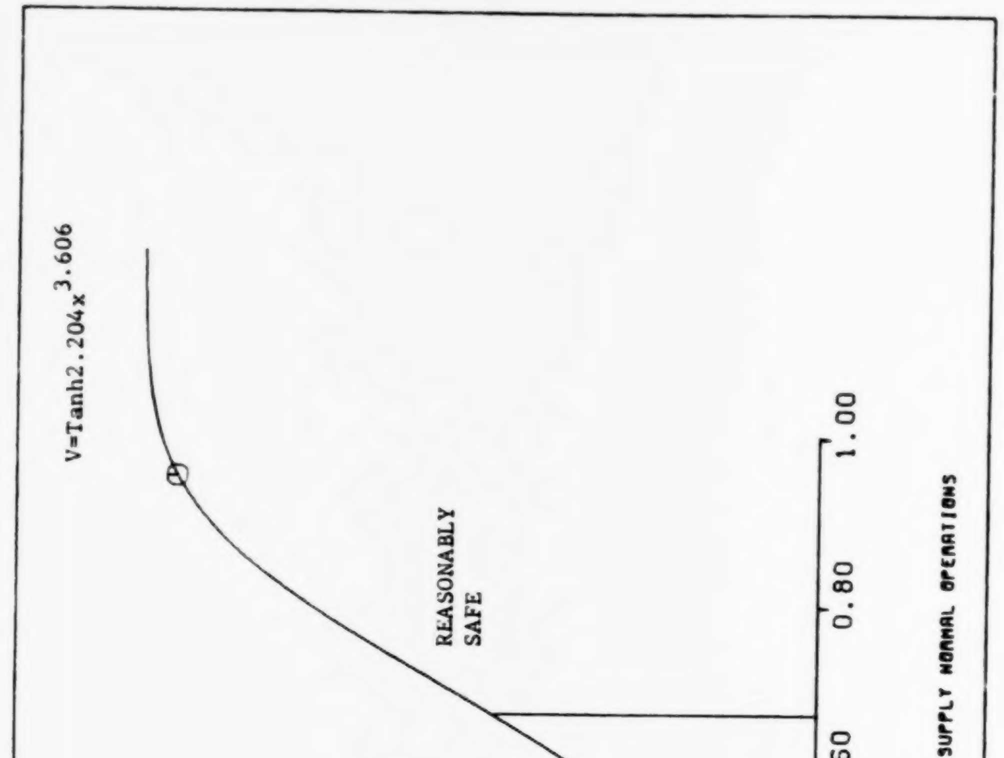
Propulsion System Safety - Curve 5.1
Safety-Energy Supply Normal Operation - Curve 5.2
Safety-Energy Supply High Speed Accident - Curve 5.3
Safety-Energy Supply Low Speed Accident - Curve 5.4
Safety - Production - Curve 5.5
Safety - Service - Curve 5.6



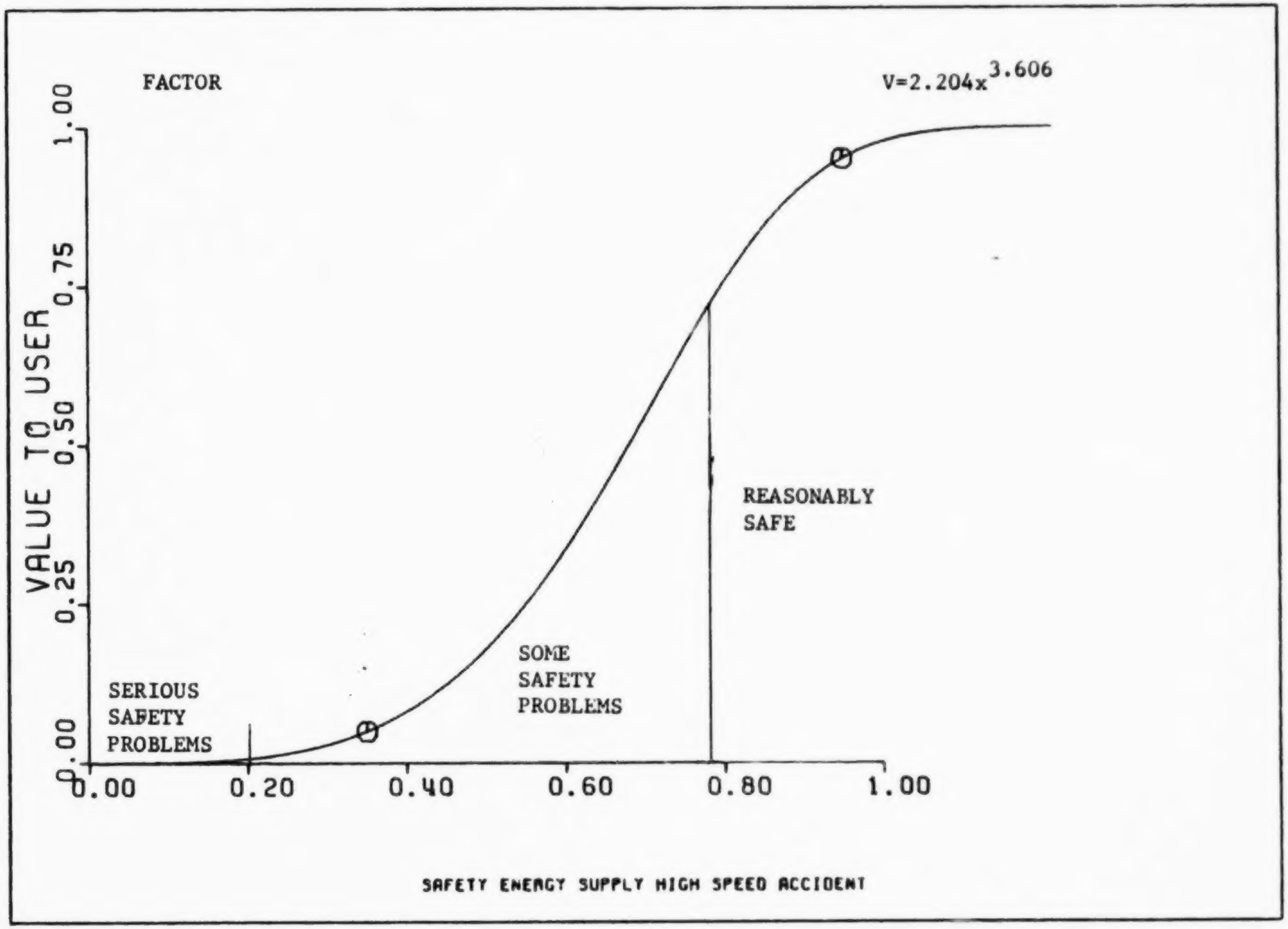
BINARY SCALE:

HAZARDOUS FAILURE OF PROPULSION SYSTEM POSSIBLE : 0.0
HAZARDOUS FAILURE OF PROPULSION SYSTEM NOT POSSIBLE : 1.0

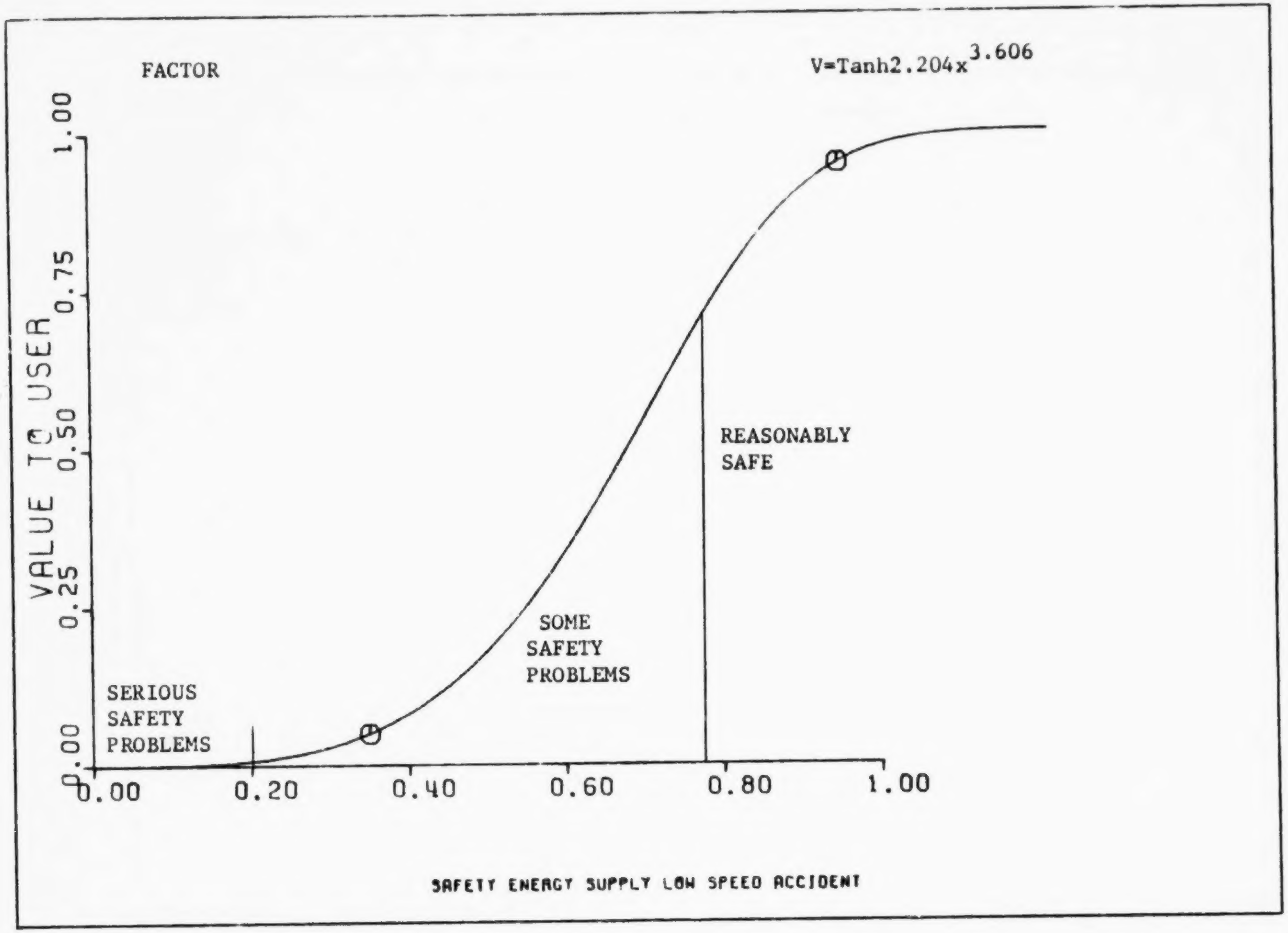
CURVE
5.1


V=Tanh2.204x$^{3.606}$
FACTOR
SERIOUS SAFETY PROBLEMS
SOME SAFETY PROBLEMS
REASONABLY SAFE
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
SAFETY ENERGY SUPPLY NORMAL OPERATIONS

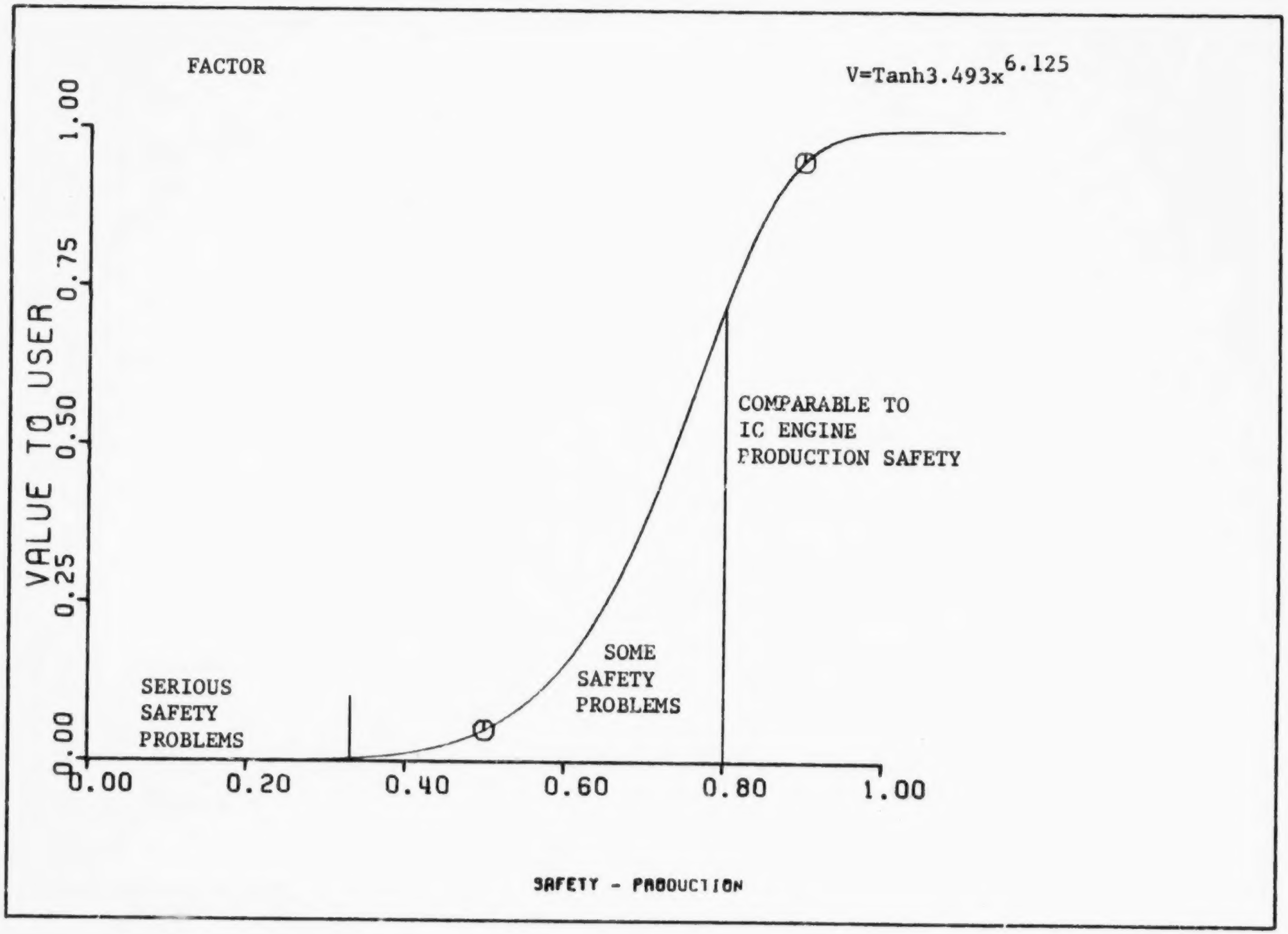
CURVE 5.2


FACTOR
V=2.204x^3.606
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.20
0.40
0.60
0.80
1.00
SERIOUS
SAFETY
PROBLEMS
SOME
SAFETY
PROBLEMS
REASONABLY
SAFE
SAFETY ENERGY SUPPLY HIGH SPEED ACCIDENT

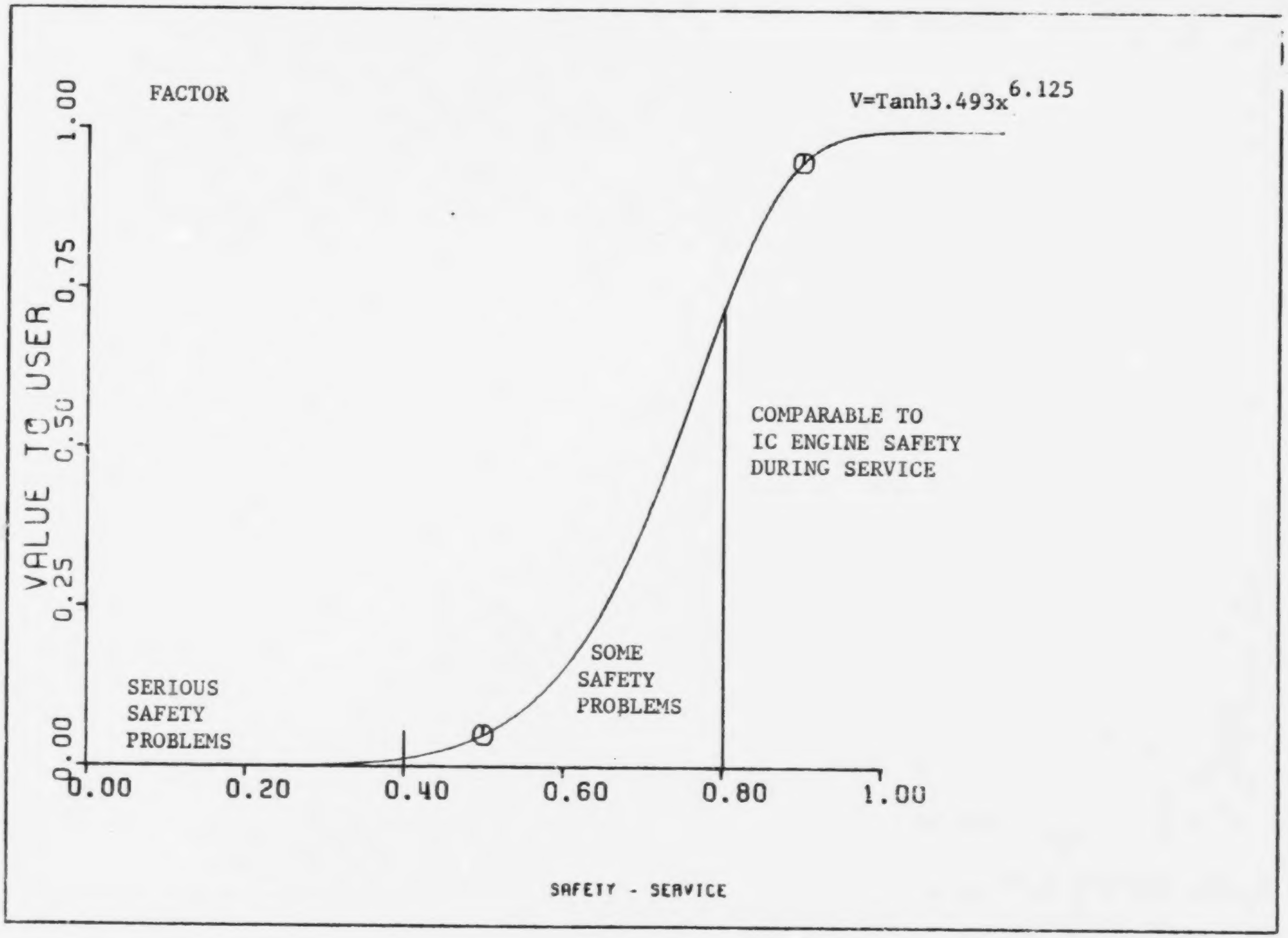
CURVE
5.3


FACTOR
V=Tanh2.204x^3.606
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.20
0.40
0.60
0.80
1.00
SERIOUS SAFETY PROBLEMS
SOME SAFETY PROBLEMS
REASONABLY SAFE
SAFETY ENERGY SUPPLY LOW SPEED ACCIDENT

CURVE
5.4


FACTOR
V=Tanh3.493x^6.125
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
SERIOUS
SAFETY
PROBLEMS
SOME
SAFETY
PROBLEMS
COMPARABLE TO
IC ENGINE
PRODUCTION SAFETY
SAFETY - PRODUCTION

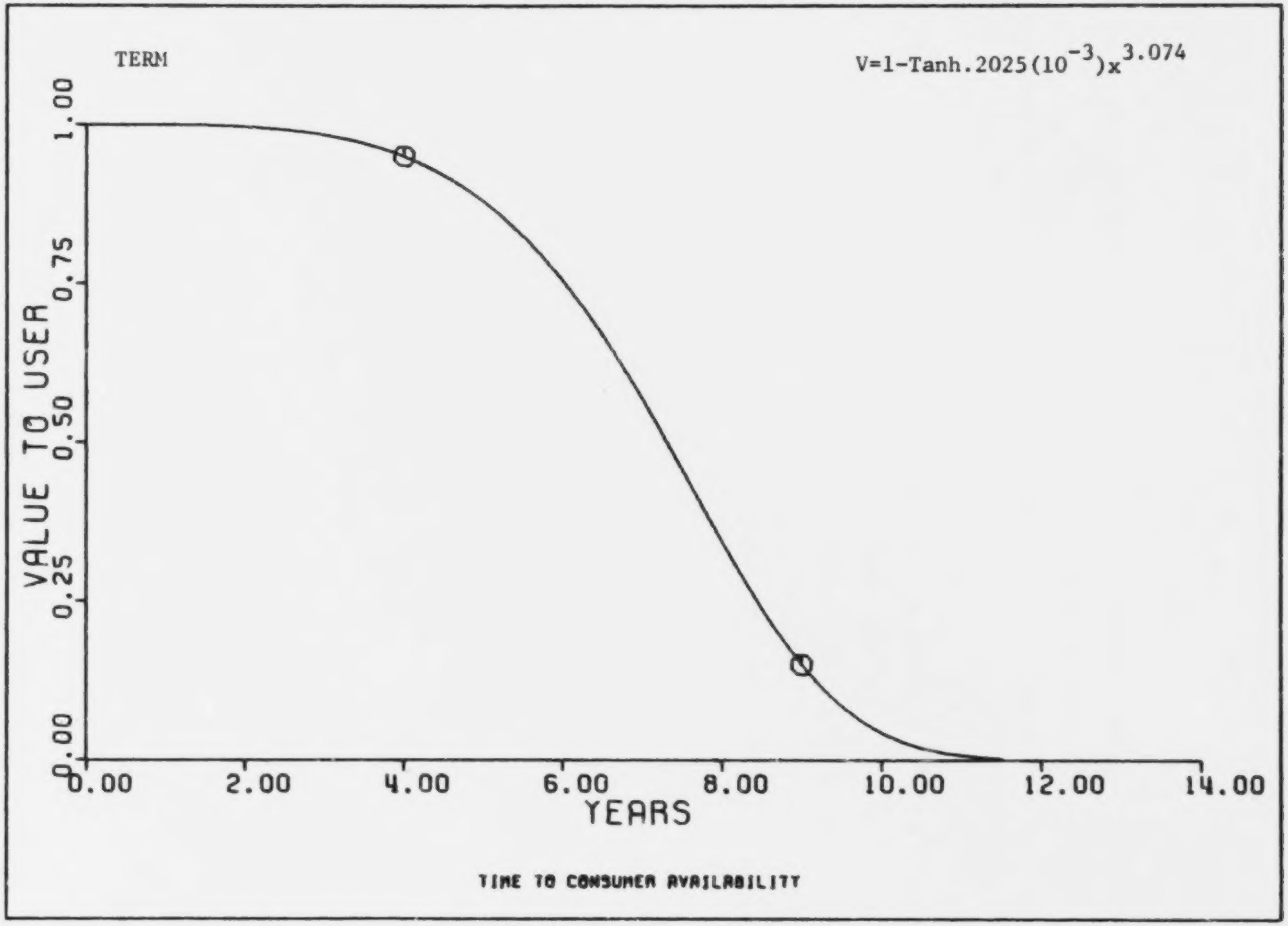
CURVE
5.5


FACTOR
$V=Tanh3.493x^{6.125}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
COMPARABLE TO
IC ENGINE SAFETY
DURING SERVICE
SERIOUS
SAFETY
PROBLEMS
SOME
SAFETY
PROBLEMS
0.00
0.20
0.40
0.60
0.80
1.00
SAFETY - SERVICE

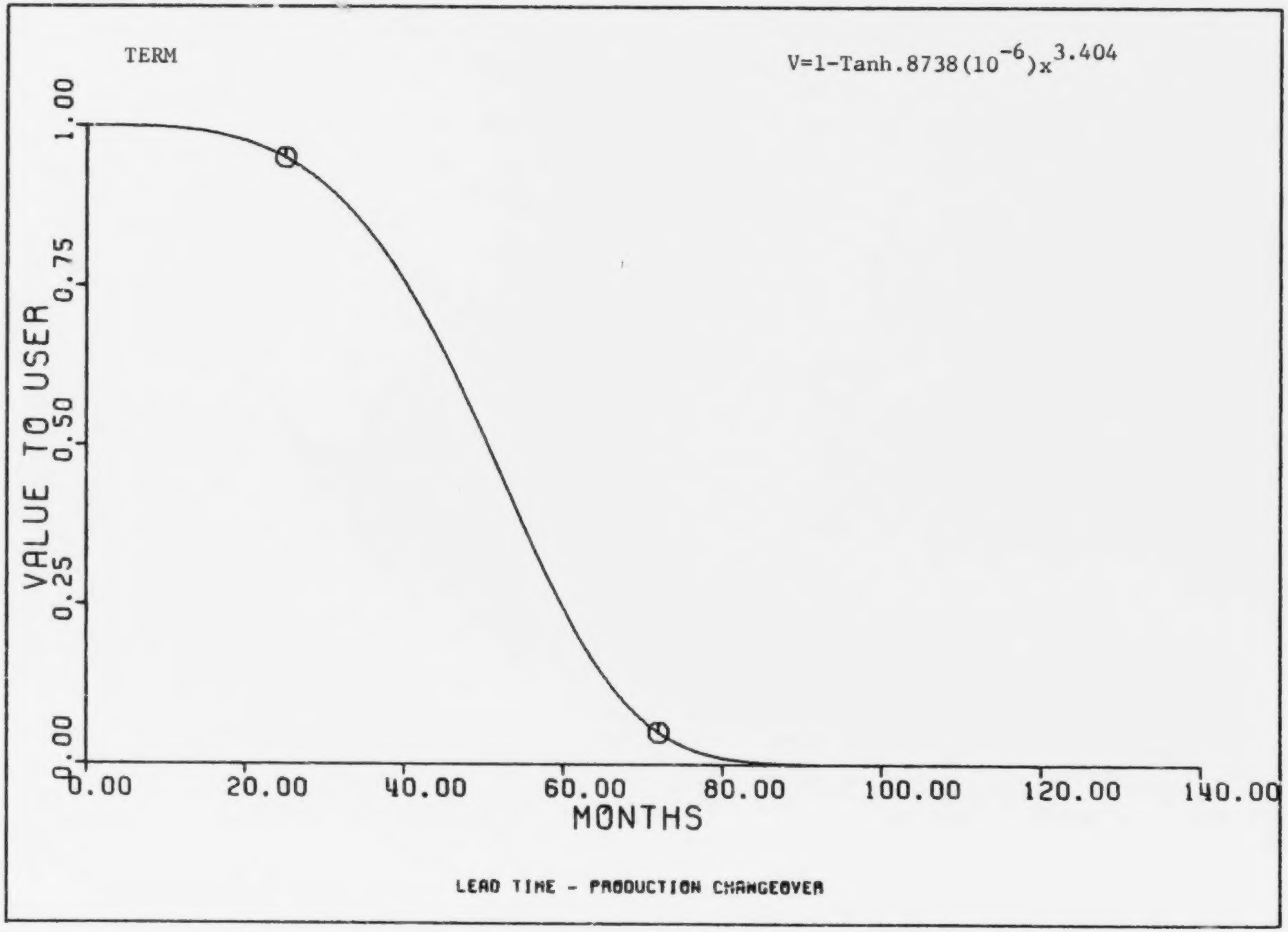
CURVE
5.6

4.1.7 Personnel and Facilities Category

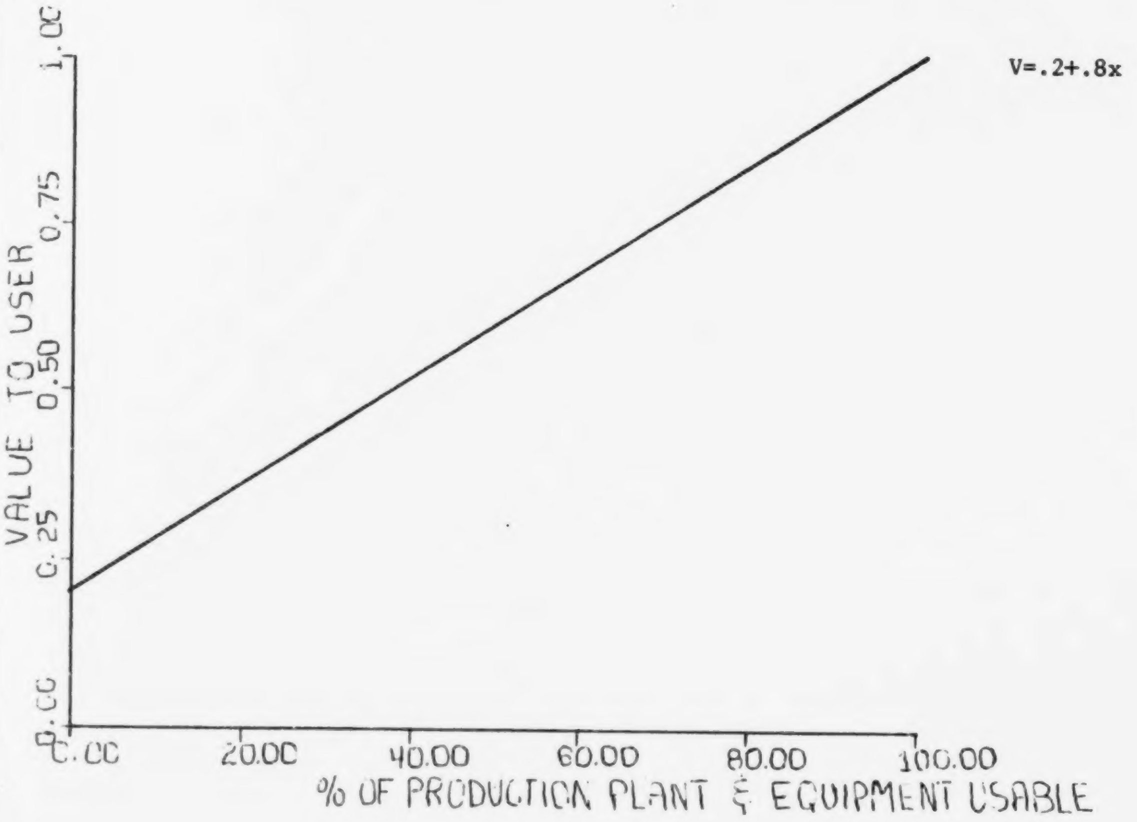
Time to Consumer Availability - Curve 6.1
Lead Time - Production Changeover - Curve 6.2
Complexity of Production Changeover - Curve 6.3
Lead Time - Field Service Changeover - Curve 6.4
Complexity of Field Service Changeover - Curve 6.5
Lead Time for Production Training - Curve 6.6
Education Level - Production - Curve 6.7
Lead Time for Service Training - Curve 6.8
Education Level - Service - Curve 6.9
Availability of Energy Stations - Curve 6.10


TERM
$V=1-\text{Tanh}.2025(10^{-3})x^{3.074}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
YEARS
TIME TO CONSUMER AVAILABILITY

CURVE
6.1

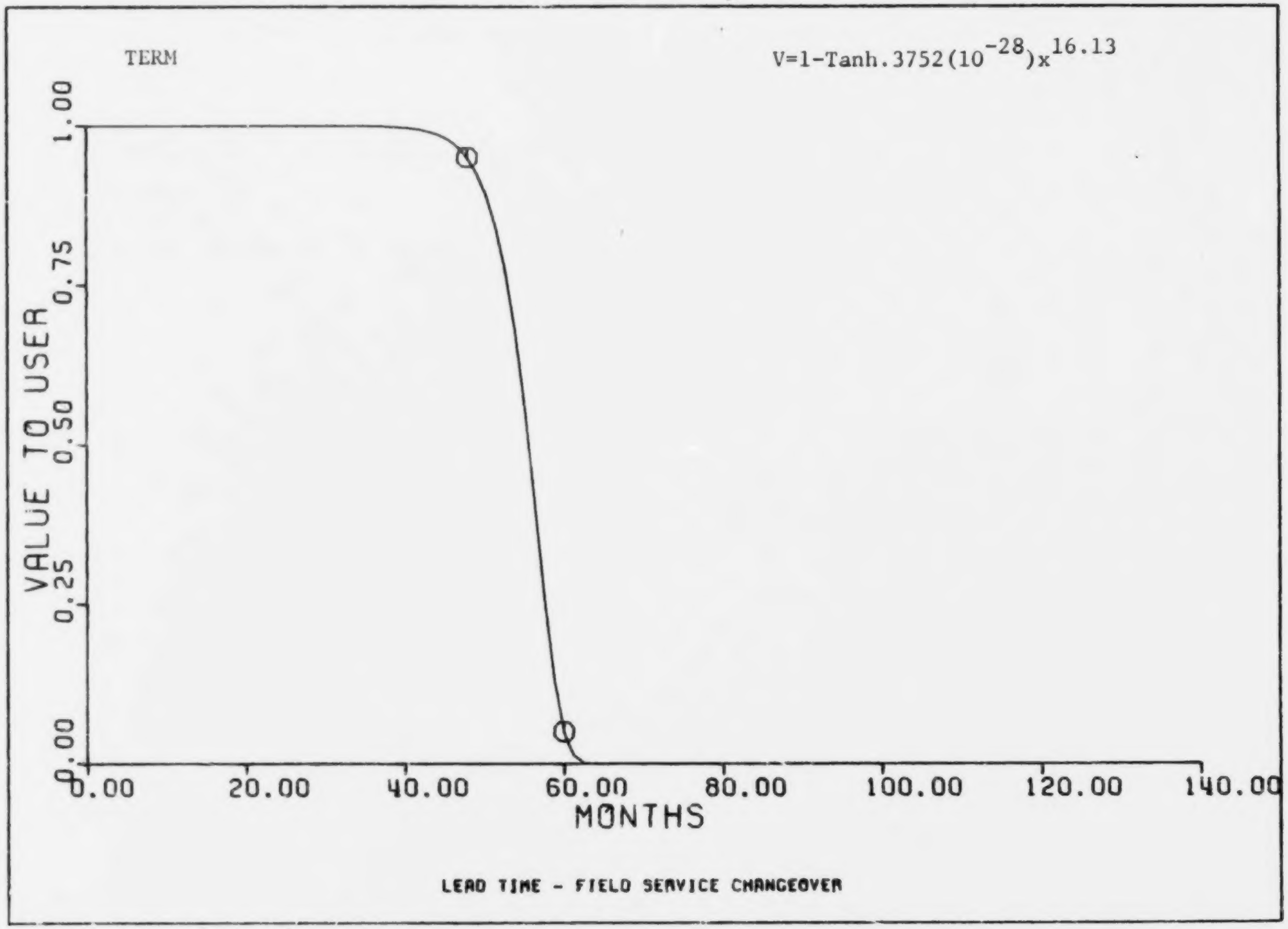

TERM
V=1-Tanh.8738(10^{-6})x$^{3.404}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
MONTHS
LEAD TIME - PRODUCTION CHANGEOVER

CURVE
6.2

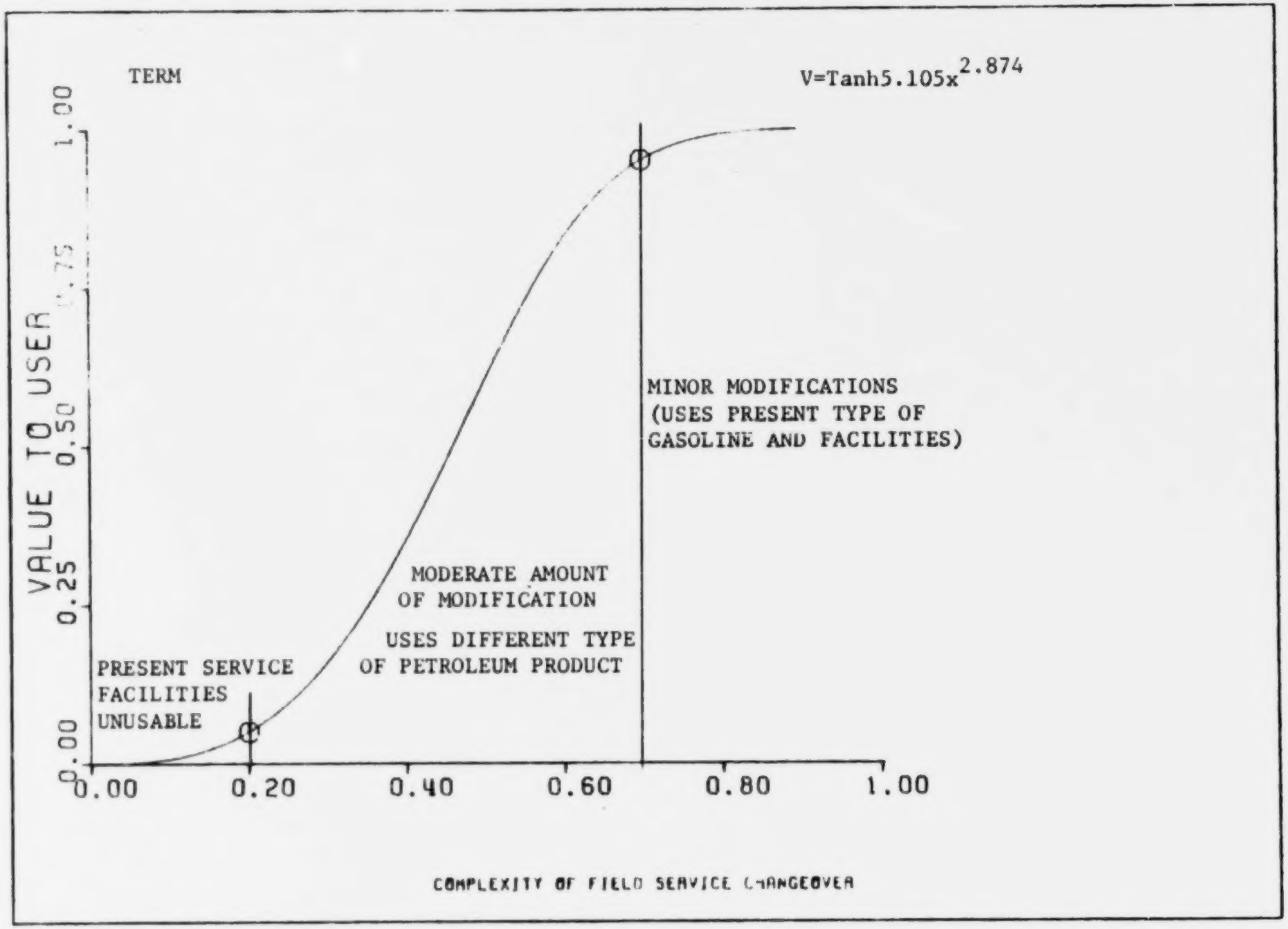


COMPLEXITY OF PRODUCTION CHANGEOVER

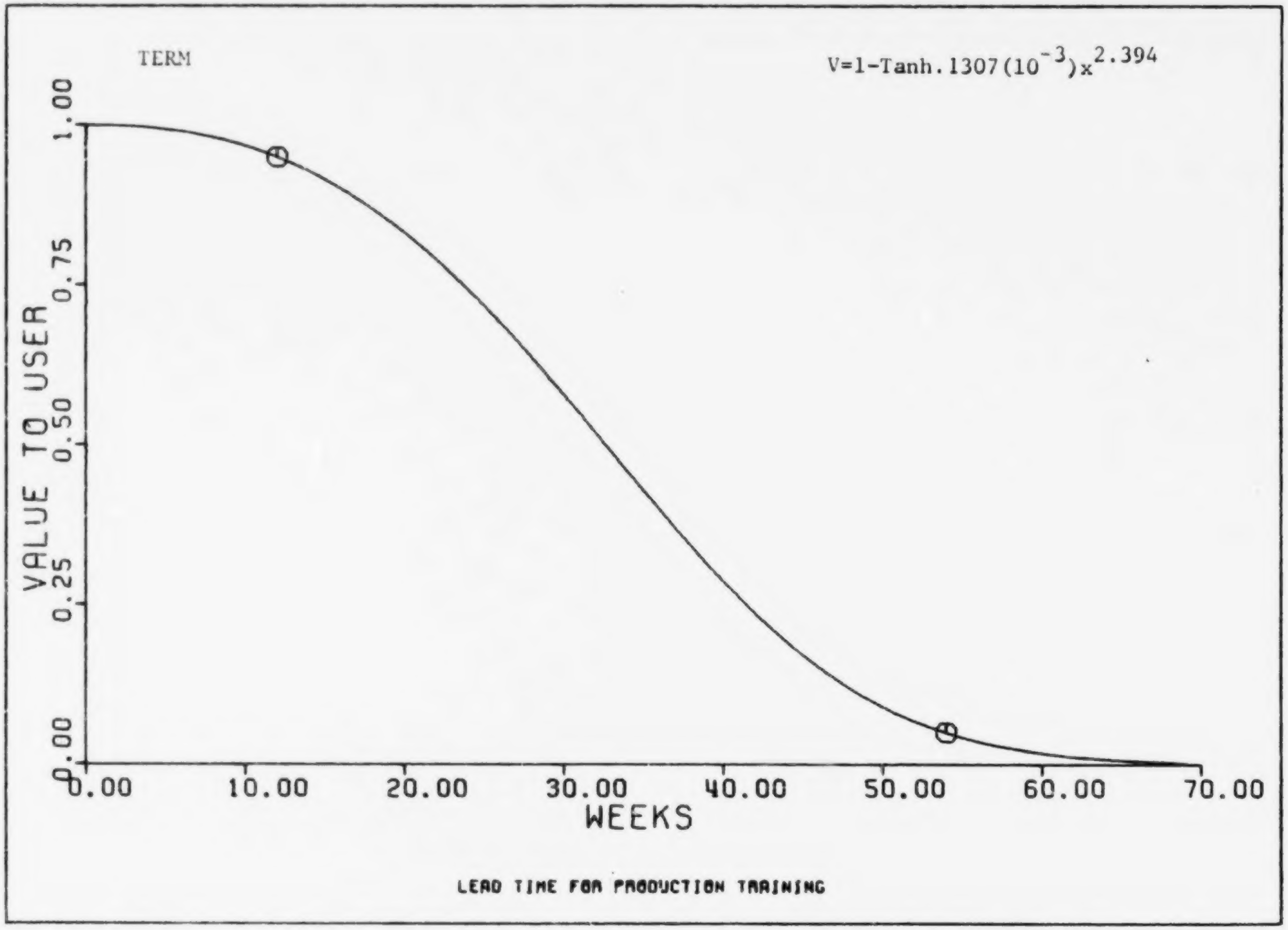
CURVE
6.3


TERM
V=1-Tanh.3752(10^-28)x^16.13
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
MONTHS
LEAD TIME - FIELD SERVICE CHANGEOVER

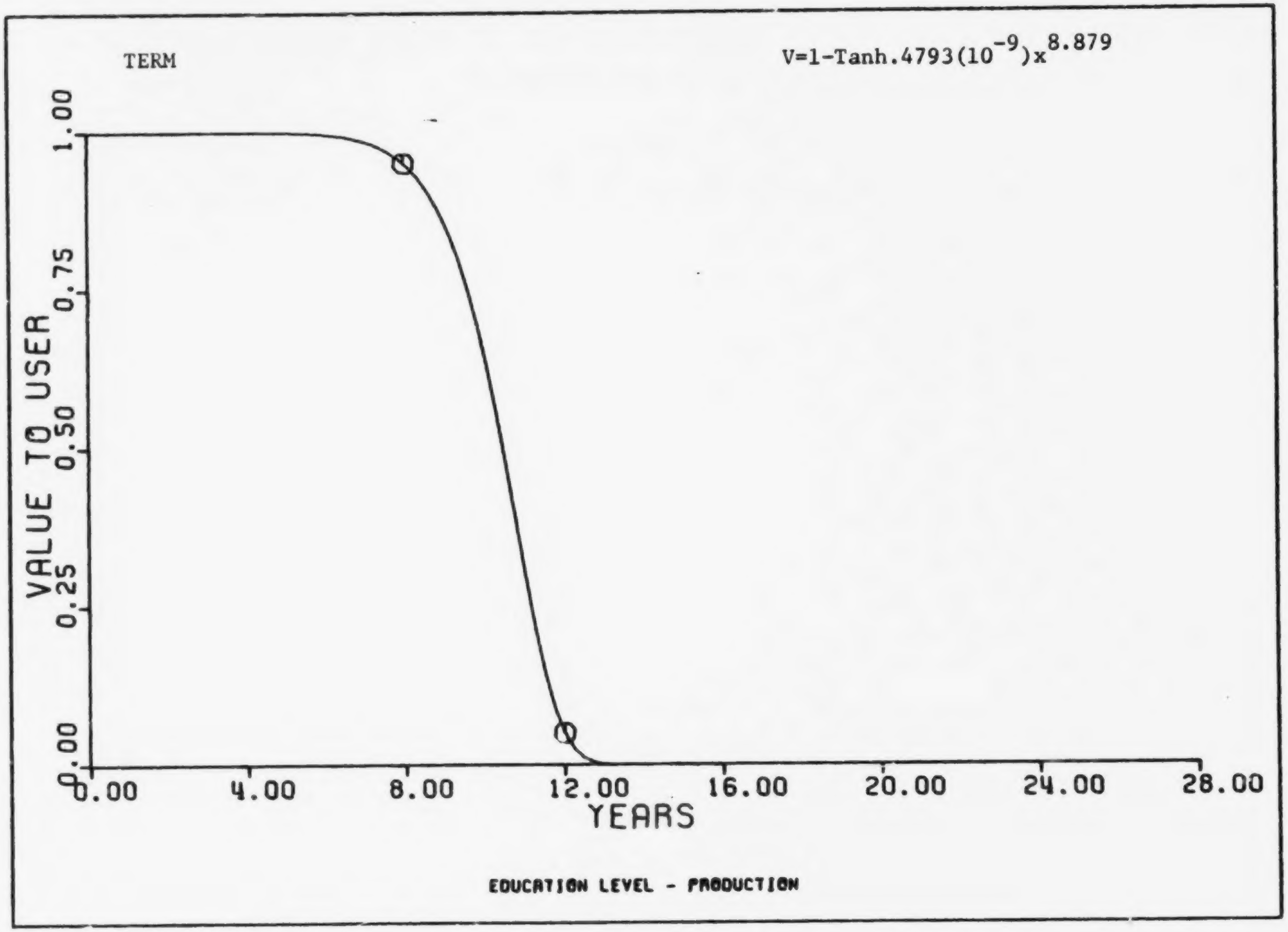
CURVE
6.4


TERM
$V=\tanh 5.105x^{2.874}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
PRESENT SERVICE
FACILITIES
UNUSABLE
MODERATE AMOUNT
OF MODIFICATION
USES DIFFERENT TYPE
OF PETROLEUM PRODUCT
MINOR MODIFICATIONS
(USES PRESENT TYPE OF
GASOLINE AND FACILITIES)
0.00
0.20
0.40
0.60
0.80
1.00
COMPLEXITY OF FIELD SERVICE CHANGEOVER

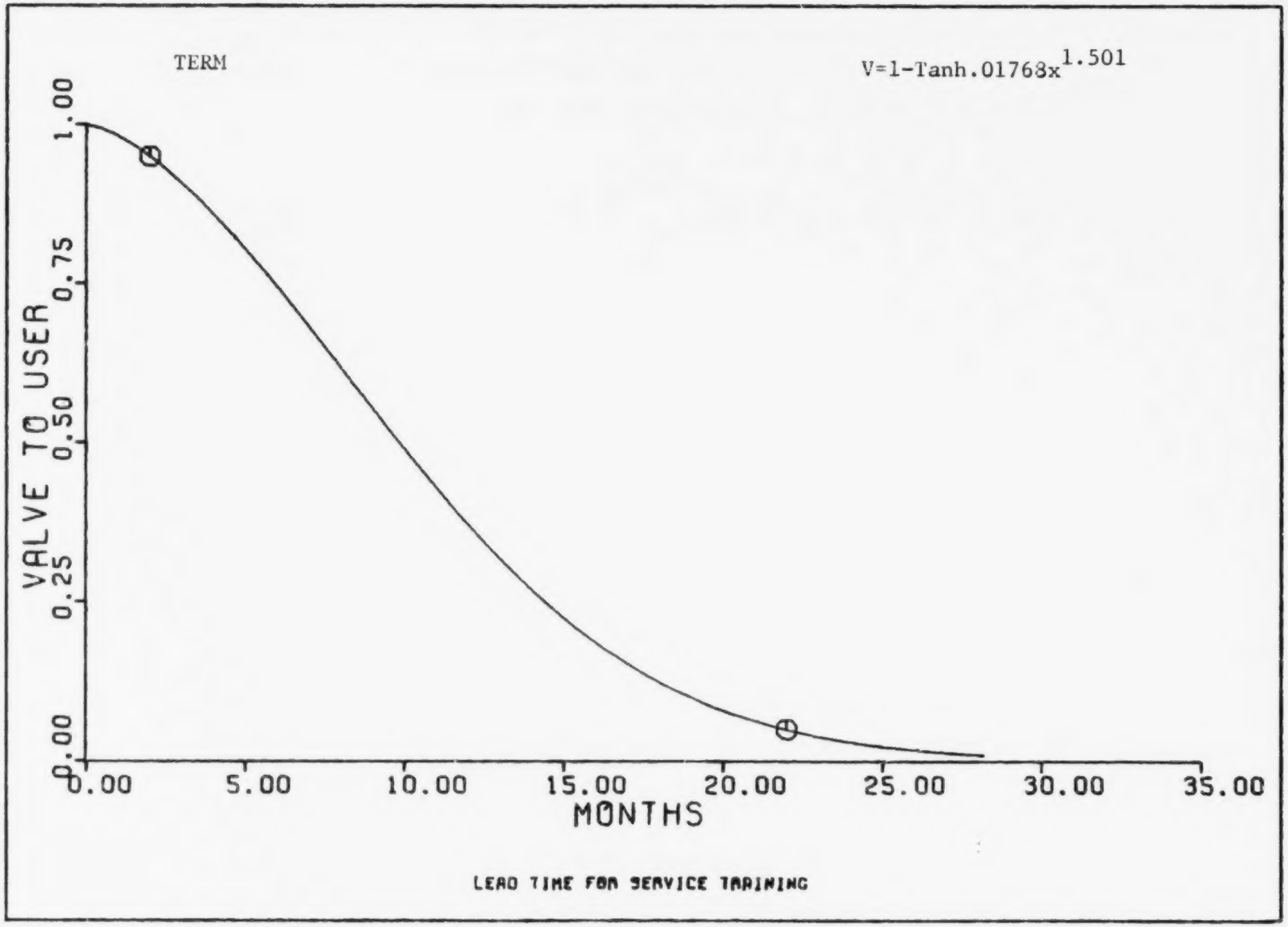
CURVE
6.5


TERM
V=1-Tanh.1307(10^-3)x^2.394
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
WEEKS
LEAD TIME FOR PRODUCTION TRAINING

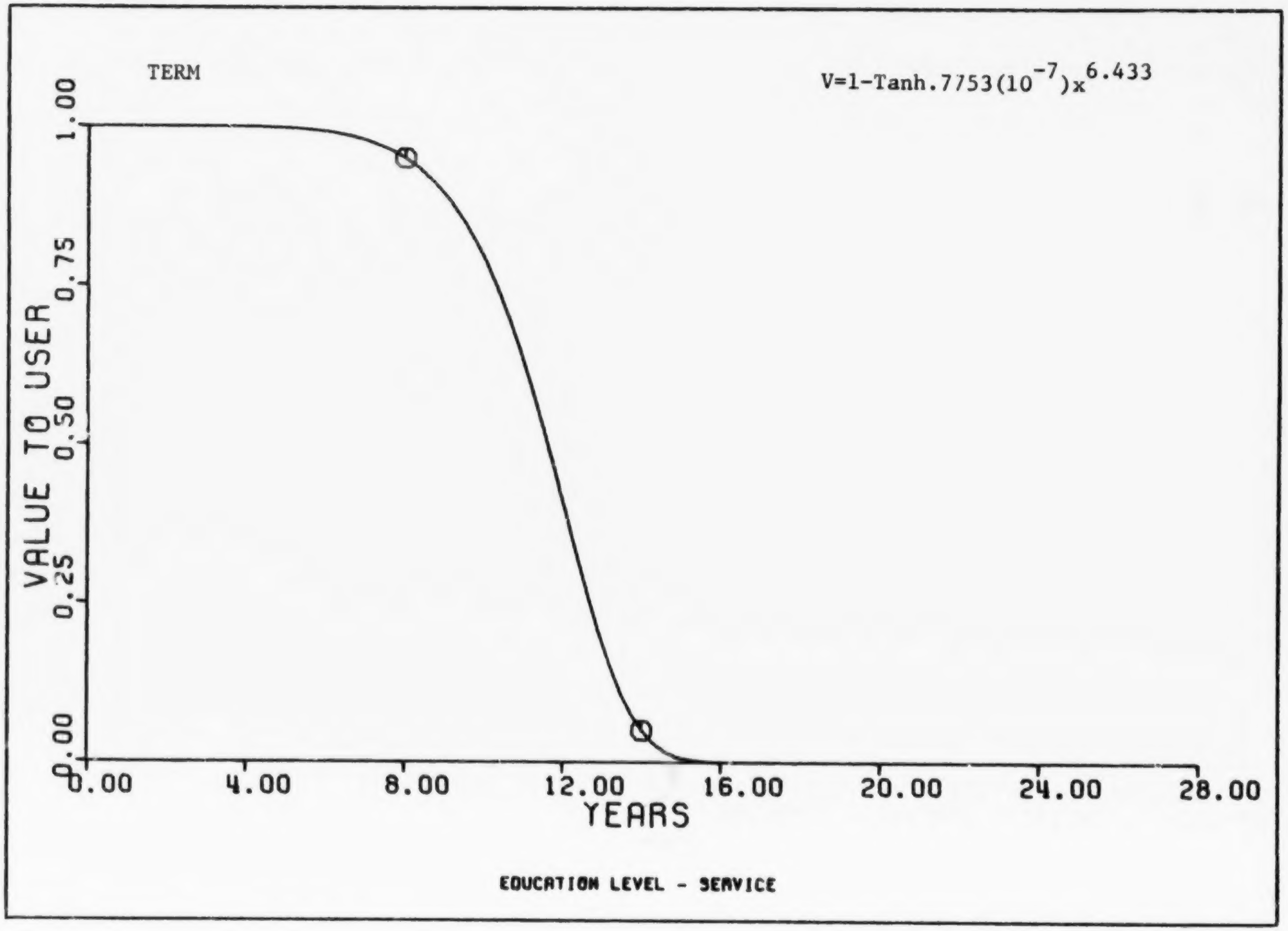
CURVE
6.6


TERM
V=1-Tanh.4793$(10^{-9})x^{8.879}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
YEARS
EDUCATION LEVEL - PRODUCTION

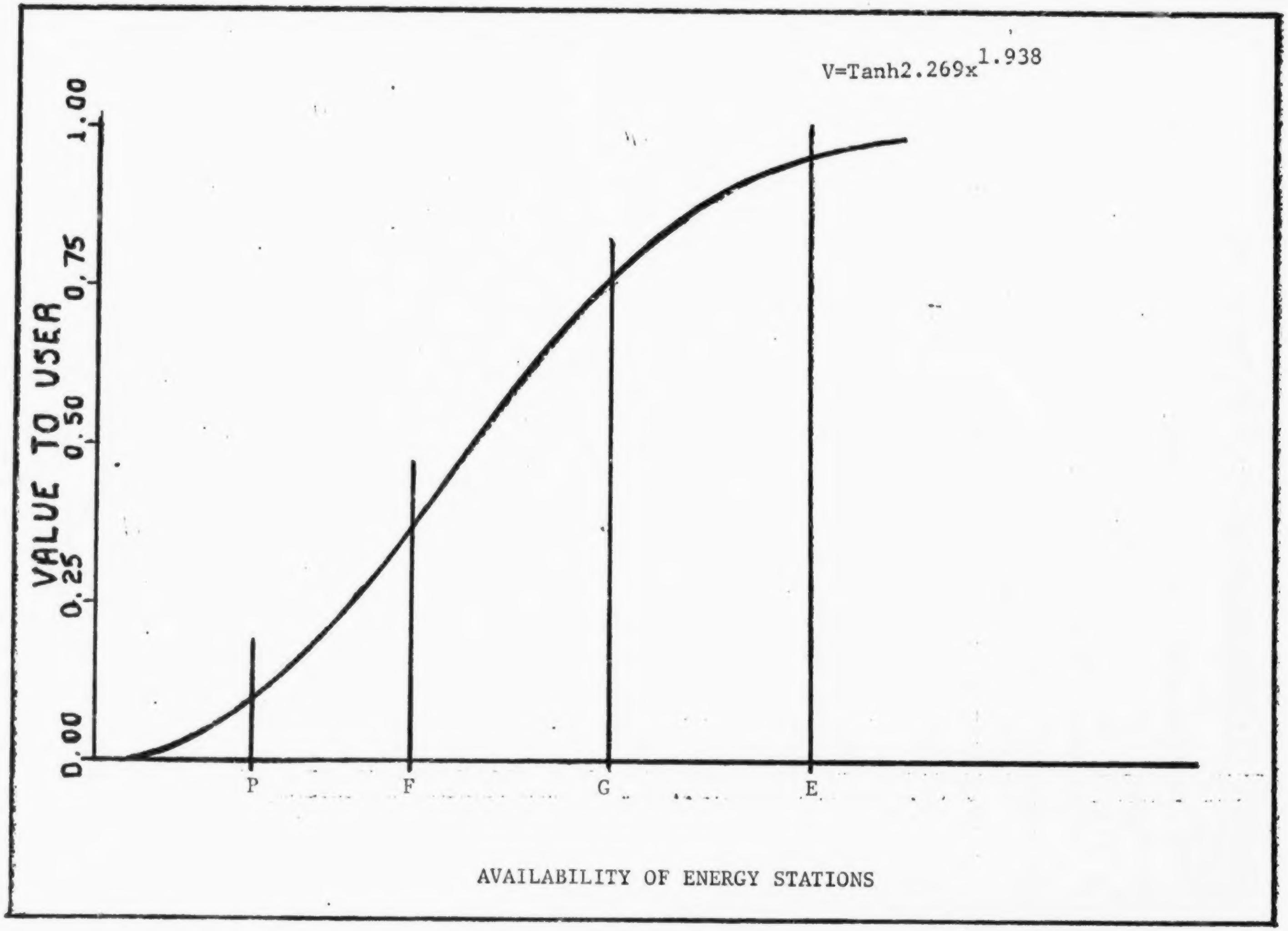
CURVE
6.7


TERM
V=1-Tanh.01768x$^{1.501}$
VALVE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
MONTHS
LEAD TIME FOR SERVICE TRAINING

CURVE
6.8


TERM
V=1-Tanh.7753(10^-7)x^6.433
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
YEARS
EDUCATION LEVEL - SERVICE

CURVE
6.9


V=Tanh2.269x^1.938
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
P
F
G
E
AVAILABILITY OF ENERGY STATIONS

CURVE
6.10

4.1.8 Propulsion System Technical Parameters

Energy Storage - Specific Volume - Curve 7.1

Energy Storage - Specific Weight - Curve 7.2

Energy Storage - Specific Cost (Consumable Elements) - Curve 7.3

Energy Storage - Specific Cost (Non-Consumable Elements) - Curve 7.4

Energy Storage - Known Fuel Reserves - Curve 7.5

Energy Storage - Ease of Refueling - Curve 7.6

Energy Converter - Specific Volume - Curve 7.7

Energy Converter - Specific Weight - Curve 7.8

Energy Converter - Specific Cost - Curve 7.9

Energy Converter - Power Range - Minimum HP - Curve 7.10

Energy Converter - Power Range - Maximum HP - Curve 7.11

Energy Converter - Stall/Design Point Torque Ratio - Curve 7.12

Energy Converter - Minimum/Design Point RPM Ratio - Curve 7.13

Energy Converter - Regeneration Power Efficiency - Curve 7.14

Energy Converter - Absorption Power Effectiveness - Curve 7.15

Energy Converter - Mechanical Efficiency at Maximum Continuous HP - Curve 7.16

Energy Converter - Response to Load Change - Curve 7.17

Energy Converter - Overload Capability - Curve 7.18

Energy Converter - Sensitivity to Fuel Quality - Curve 7.19

Power Conditioner - Specific Volume - Curve 7.20

Power Conditioner - Specific Weight - Curve 7.21

Power Conditioner - Specific Cost - Curve 7.22

Power Conditioner - Power Range Minimum - Curve 7.23

Power Conditioner - Power Range Maximum - Curve 7.24

Power Conditioner - Reversing Power Effectiveness - Curve 7.25

Power Conditioner - Mechanical Efficiency at Maximum Continuous Power - Curve 7.26

Power Conditioner - Mechanical Efficiency in Reverse Power Direction - Curve 7.27

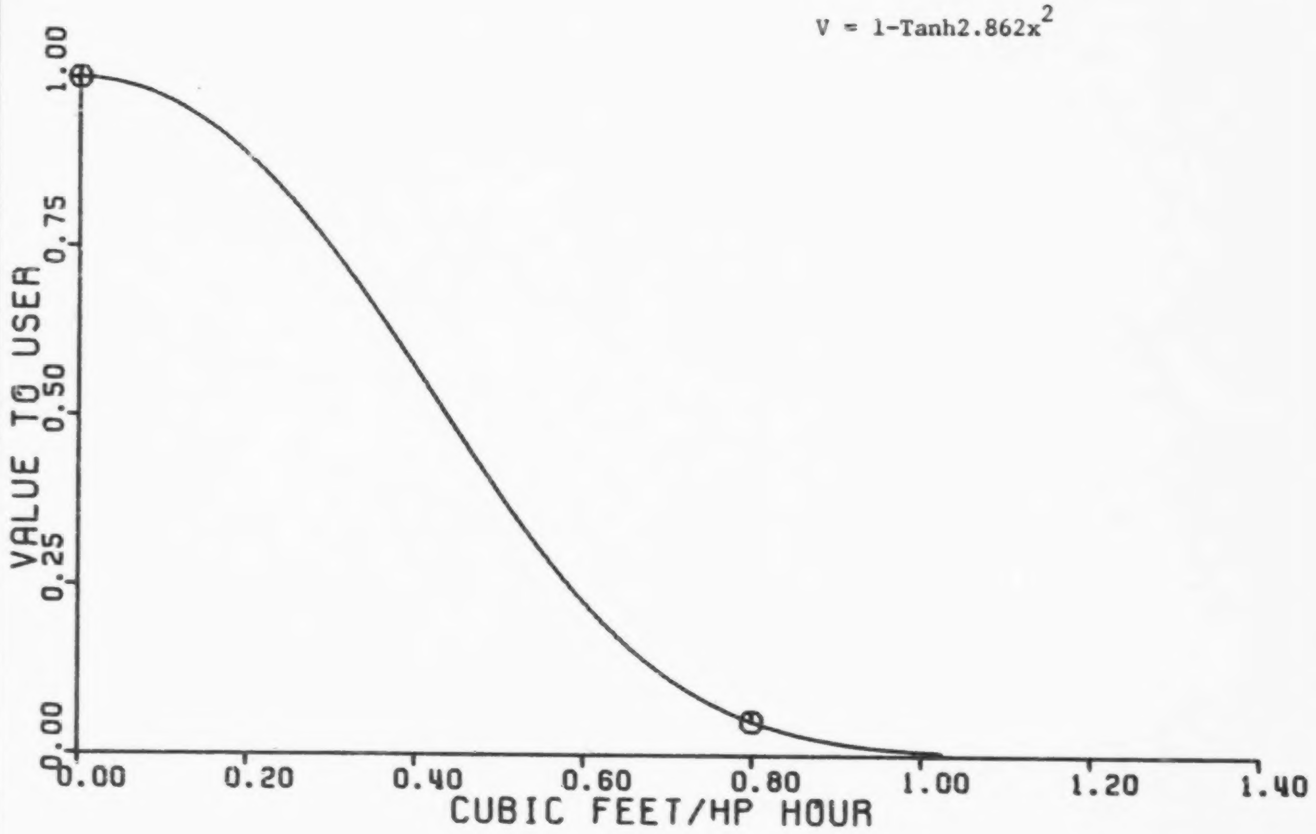
Overall Propulsion System - Average Efficiency at the Wheel, Mode 1 - Curve 7.28

Overall Propulsion System - Average Efficiency at the Wheel, Mode 2 - Curve 7.29

Overall Propulsion System - Total Volume - Curve 7.30

Overall Propulsion System - Total Weight - Curve 7.31

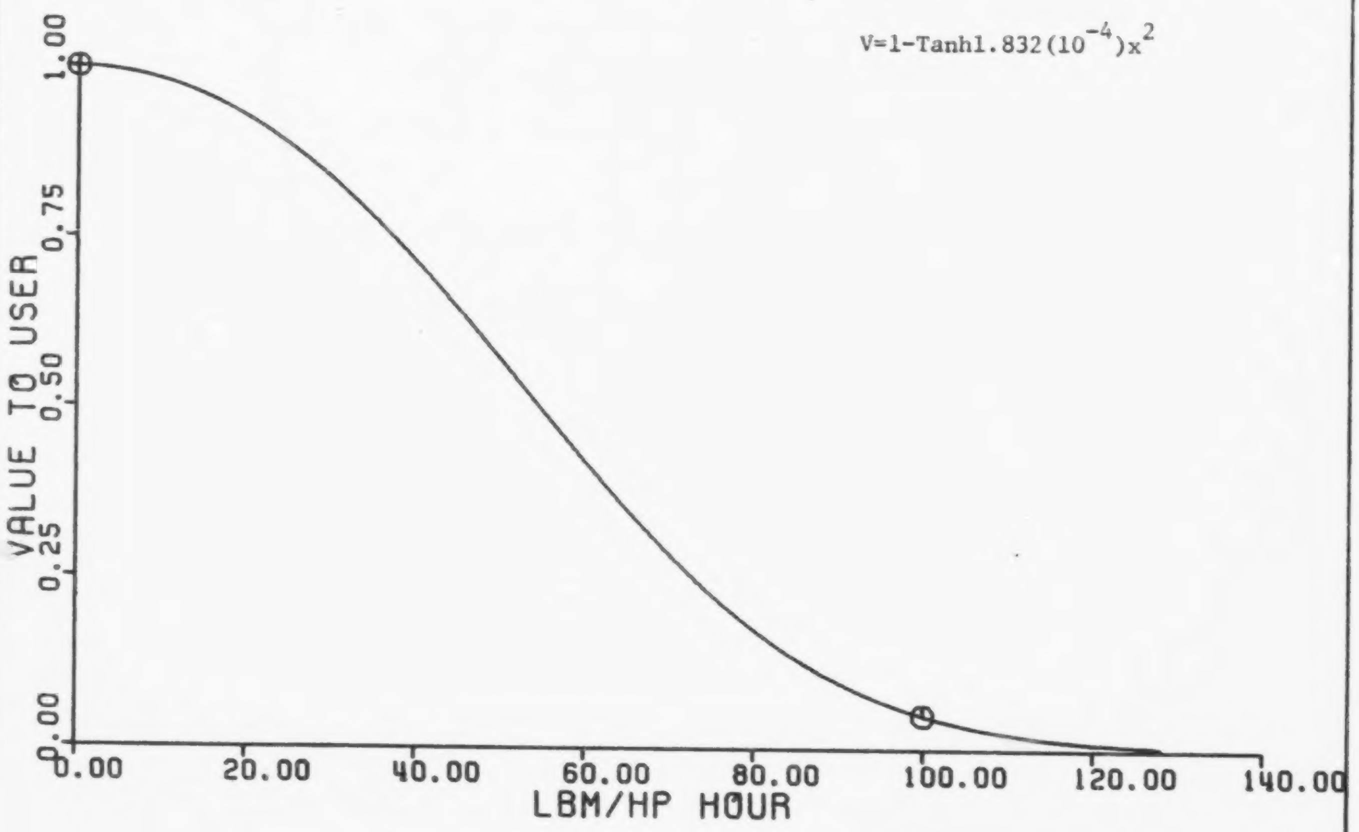
Overall Propulsion System - Use of Scarce Materials - Curve 7.32



ENERGY STORAGE - SPECIFIC VOLUME

CURVE

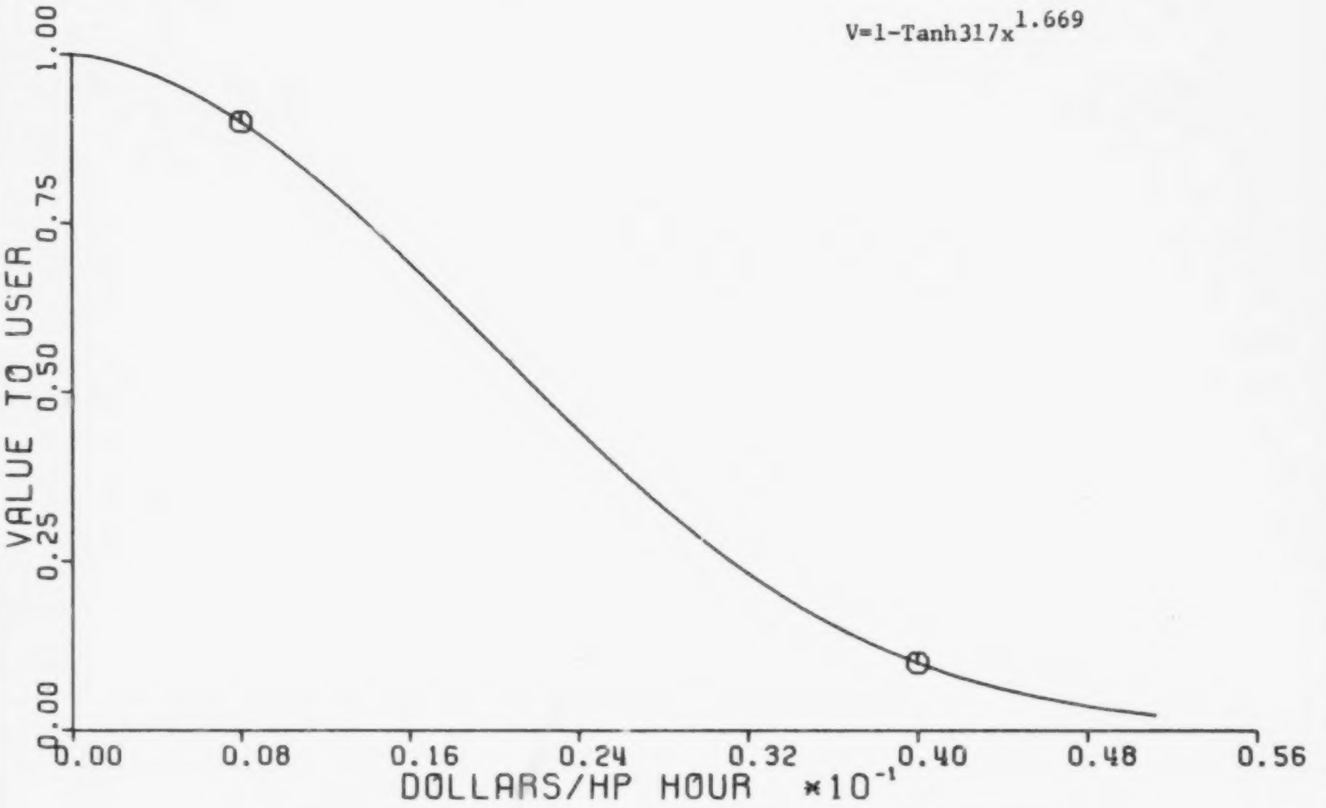
7.1



ENERGY STORAGE - SPECIFIC WEIGHT

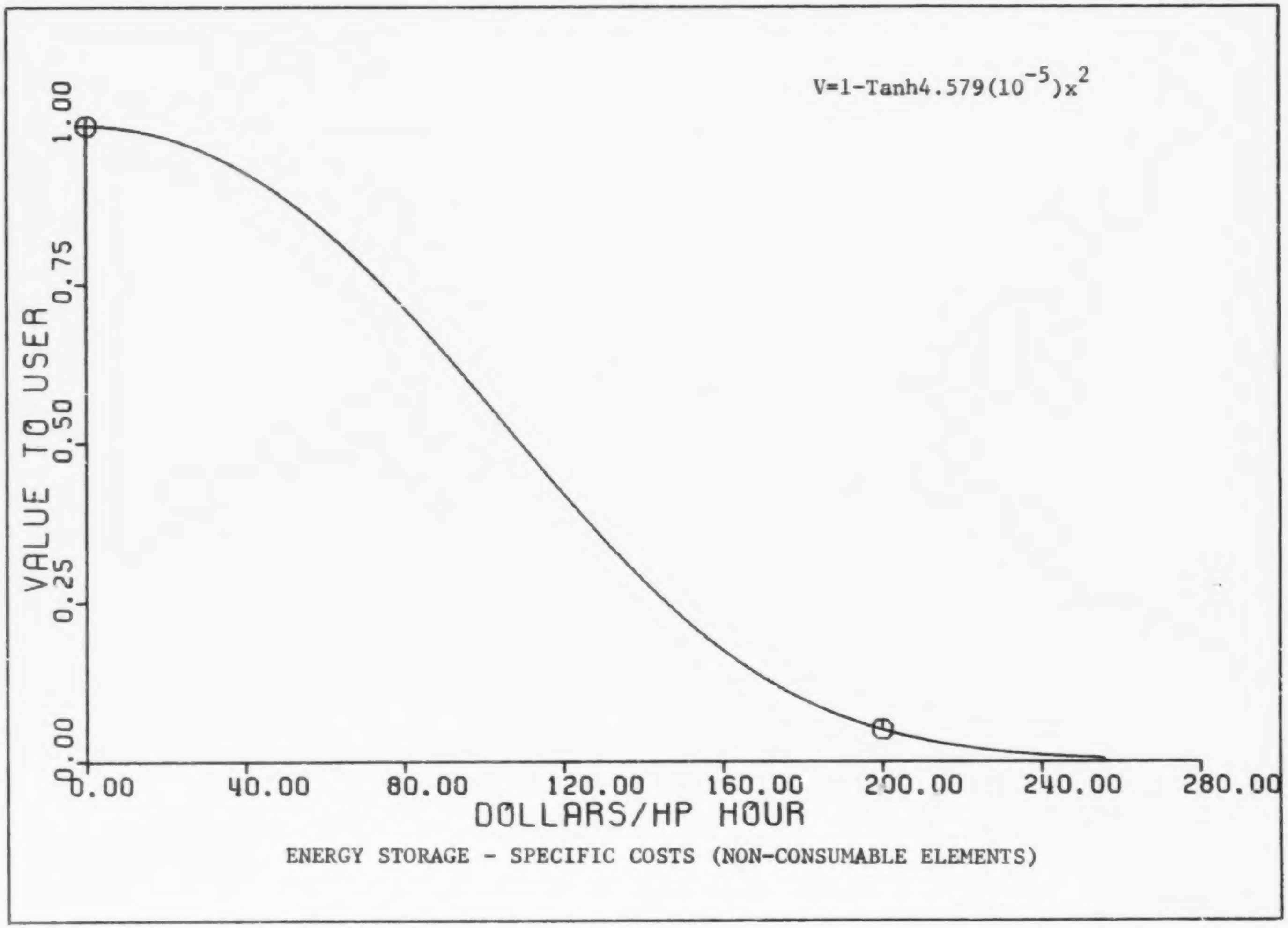
CURVE

7.2



ENERGY STORAGE - SPECIFIC COSTS (CONSUMABLE ELEMENTS)

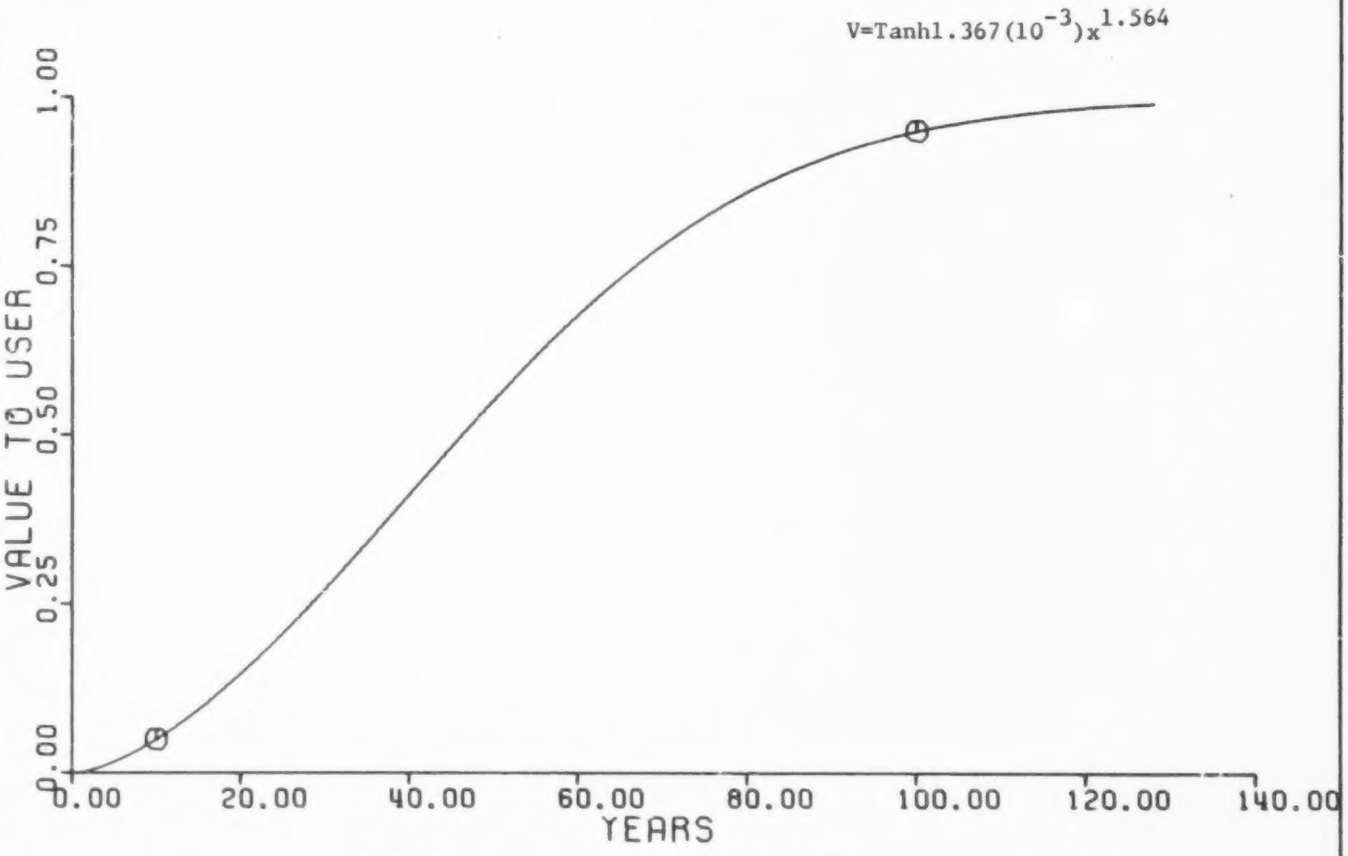
CURVE
7.3



ENERGY STORAGE - SPECIFIC COSTS (NON-CONSUMABLE ELEMENTS)

CURVE

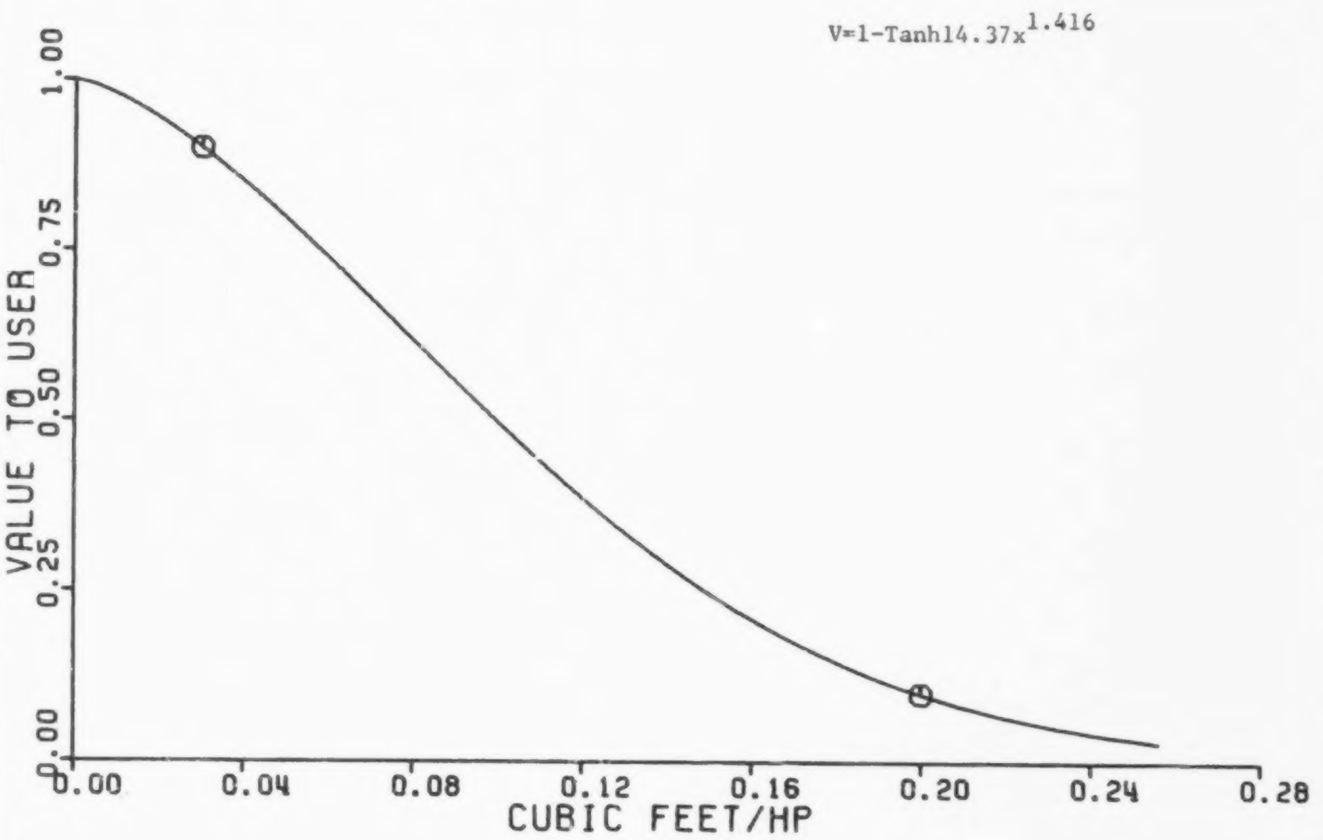
7.4



ENERGY STORAGE - KNOWN FUEL RESERVES

CURVE

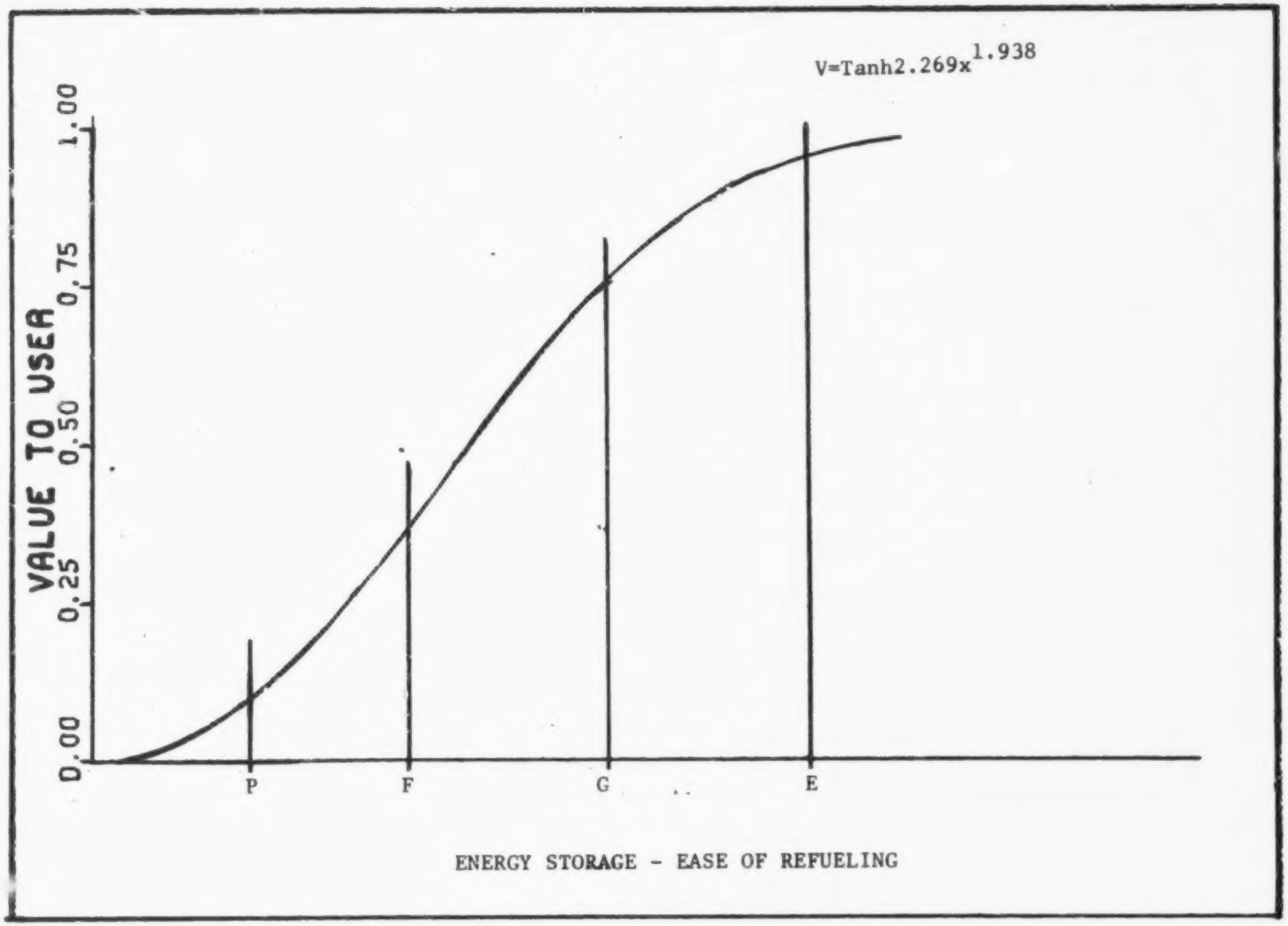
7.5



ENERGY CONVERTER - SPECIFIC VOLUME

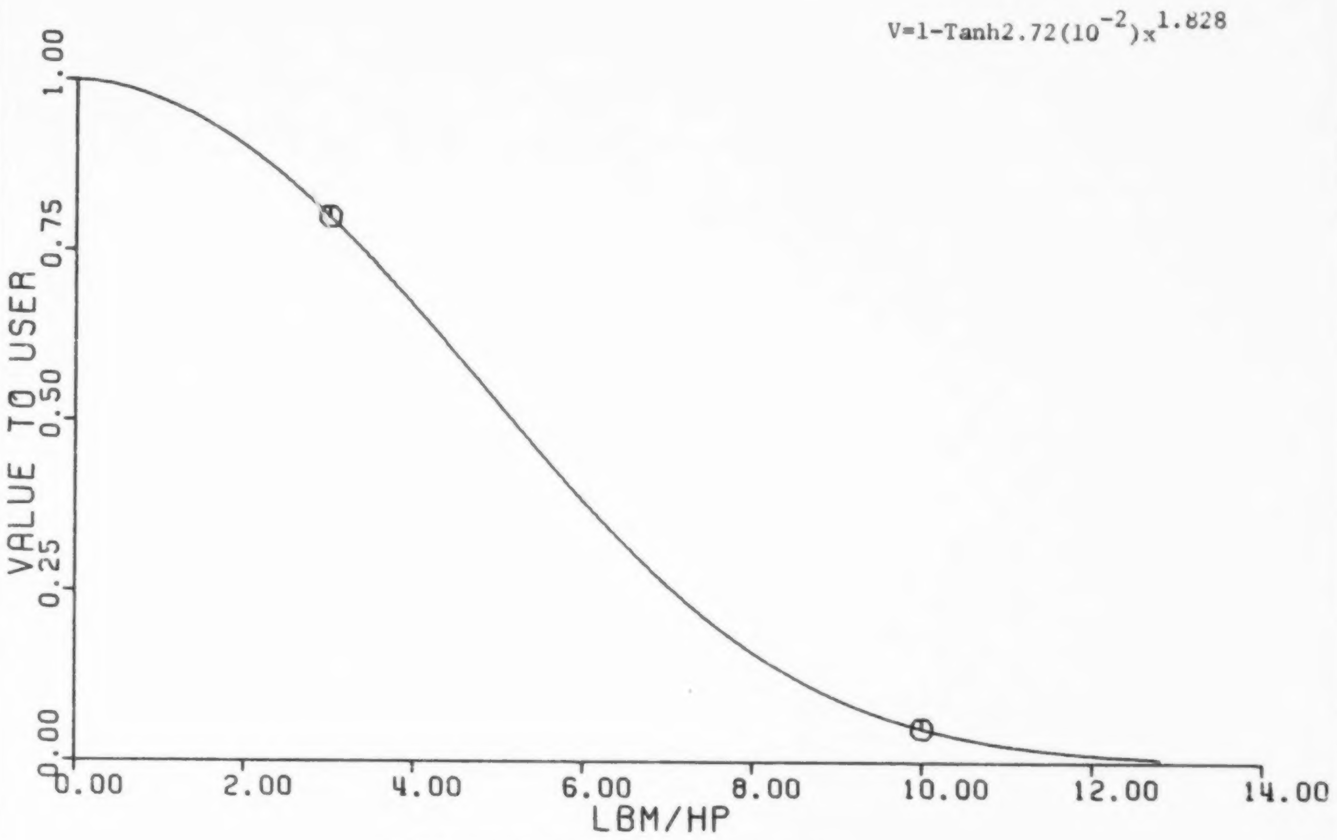
CURVE

7.7


V=Tanh2.269x^1.938
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
P
F
G
E
ENERGY STORAGE - EASE OF REFUELING

CURVE

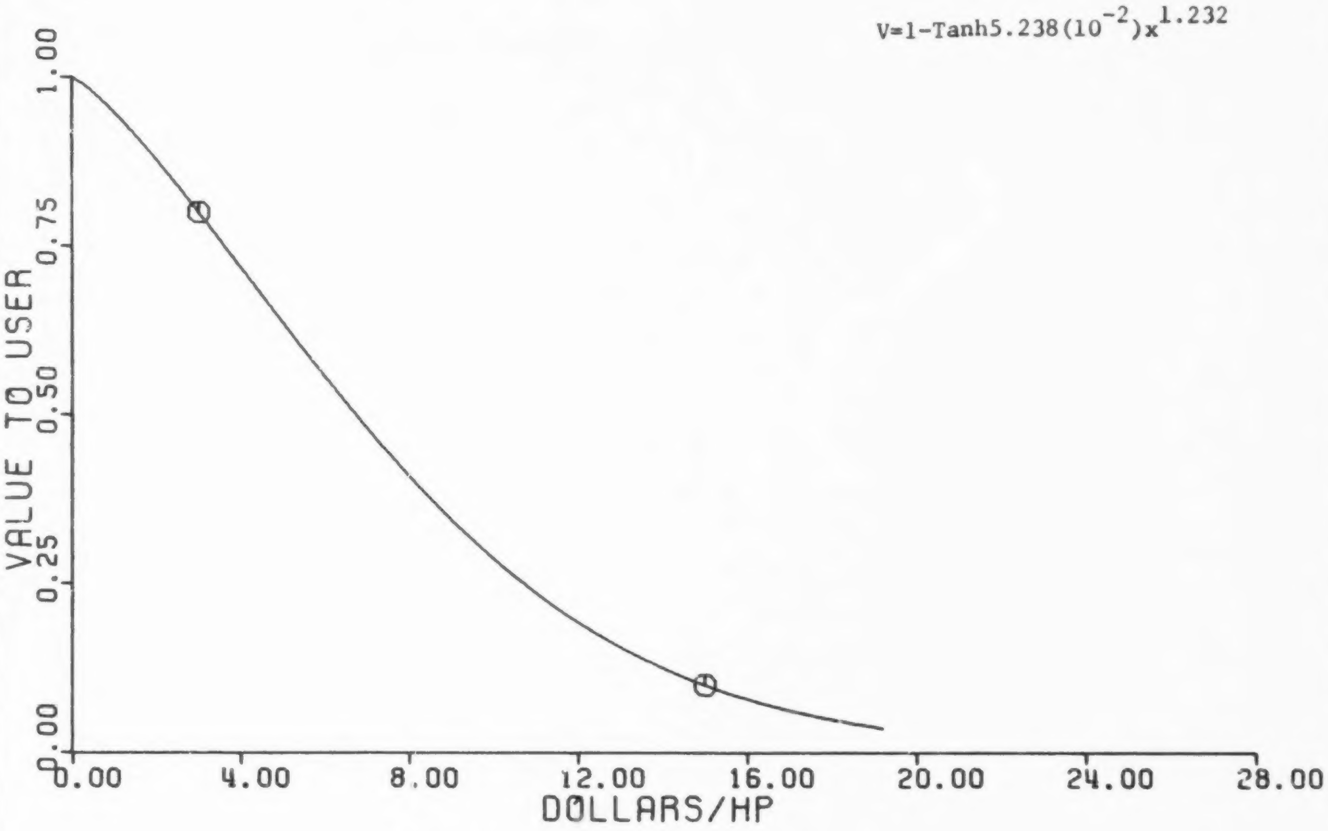
7.6



ENERGY CONVERTER - SPECIFIC WEIGHT

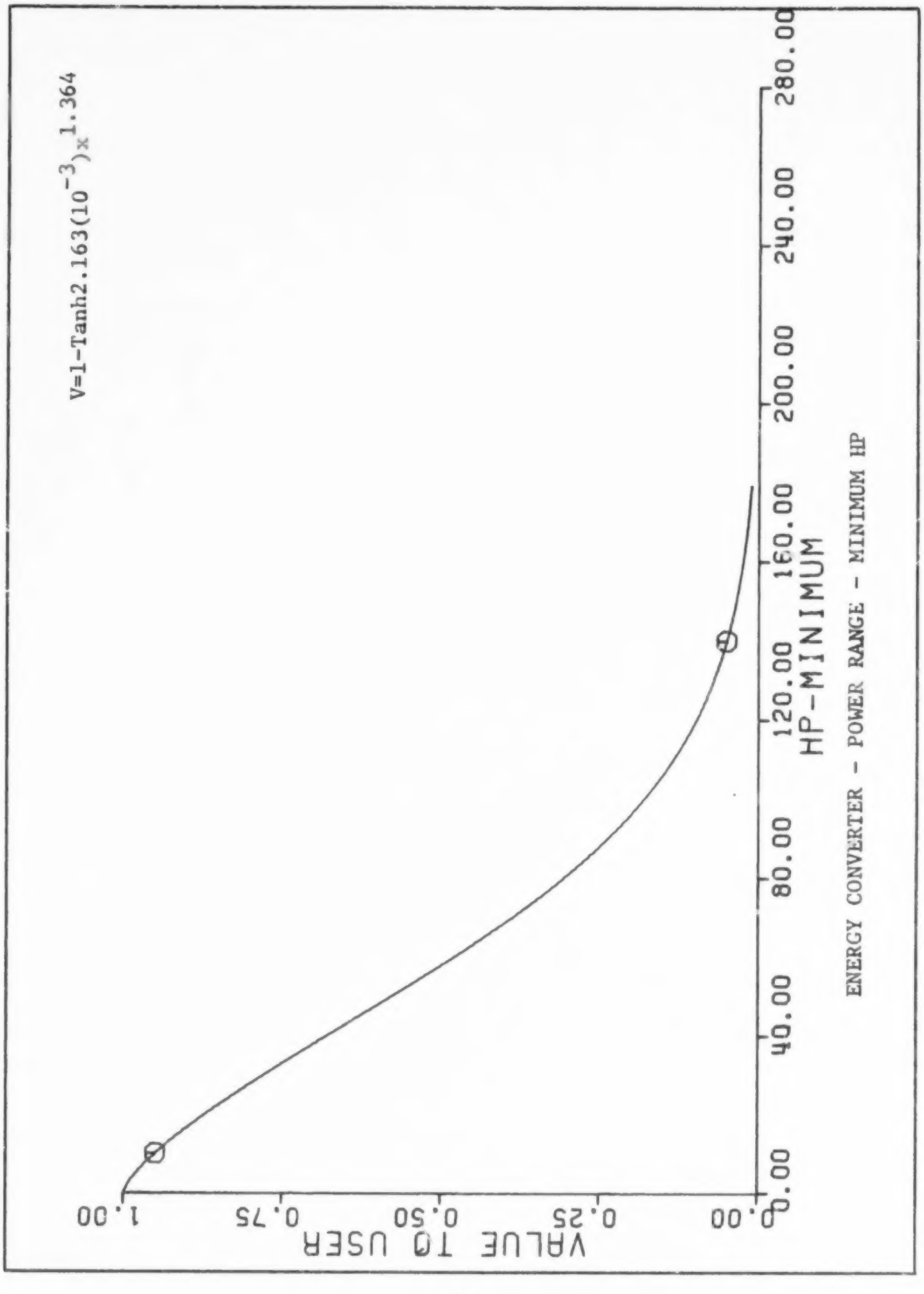
CURVE

7.8



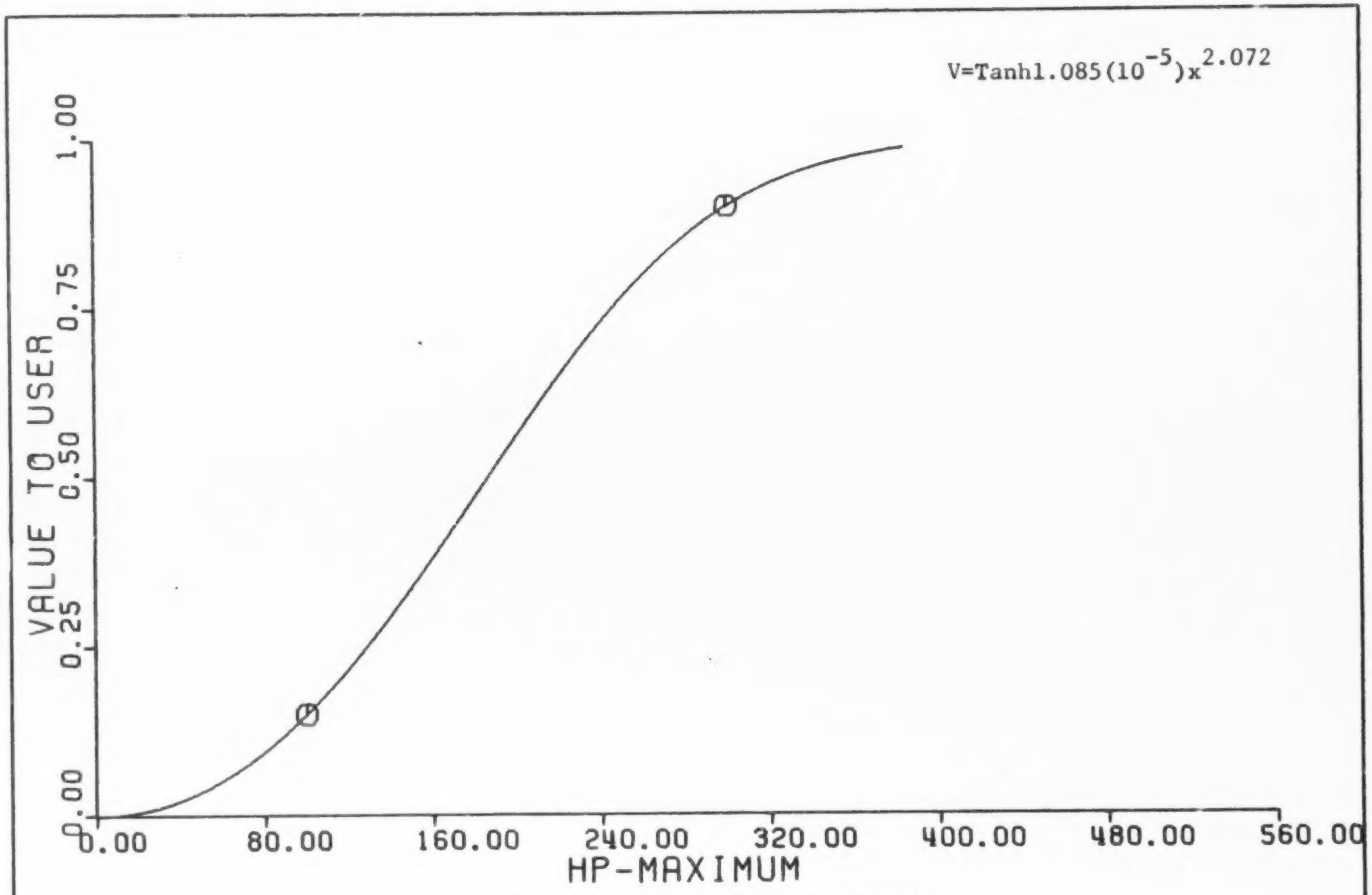
ENERGY CONVERTER - SPECIFIC COST

CURVE
7.9



ENERGY CONVERTER - POWER RANGE - MINIMUM HP

CURVE
7.10

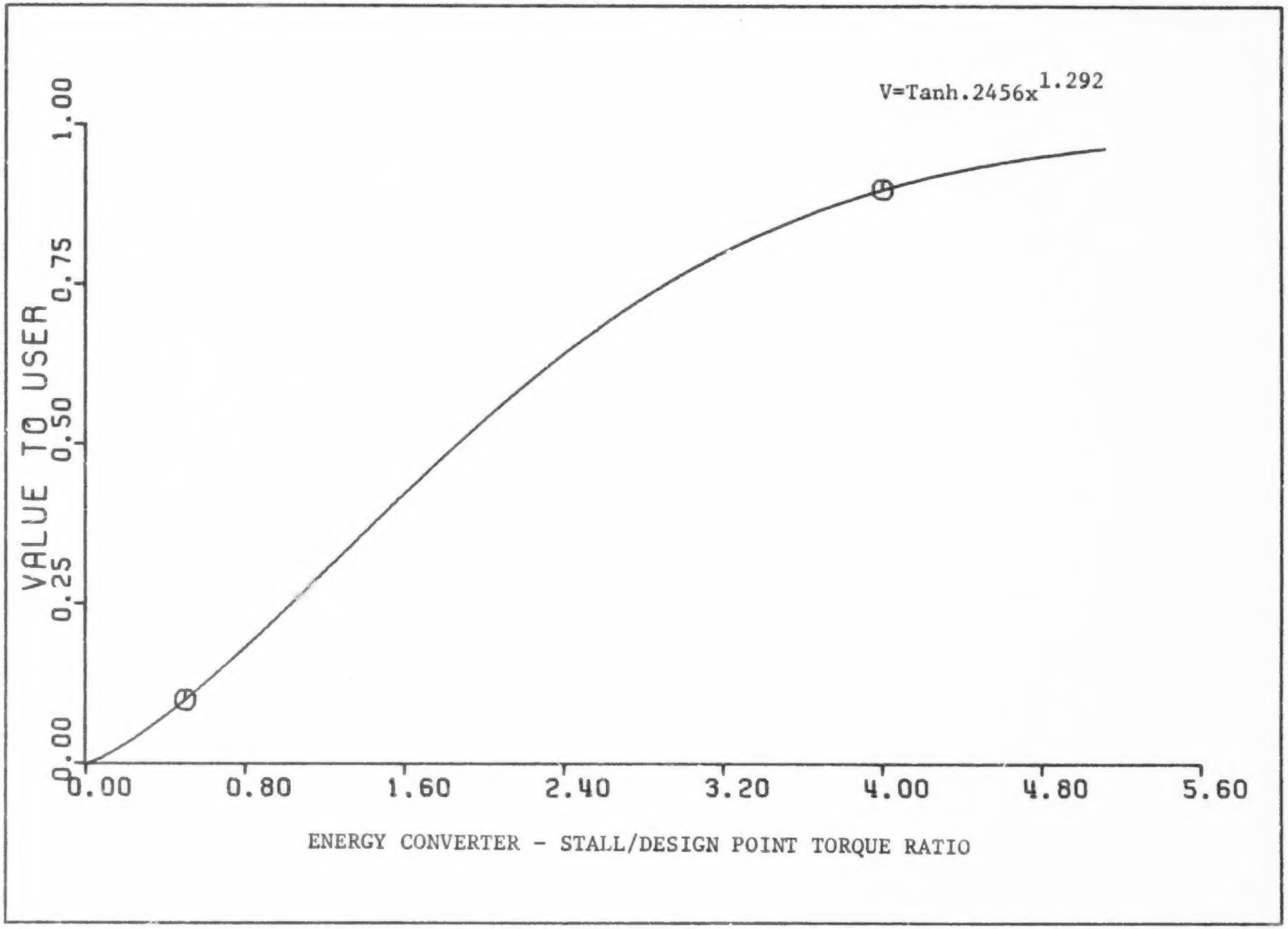


$V = \text{Tanh}\,1.085(10^{-5})x^{2.072}$

ENERGY CONVERTER - POWER RANGE - MAXIMUM HP

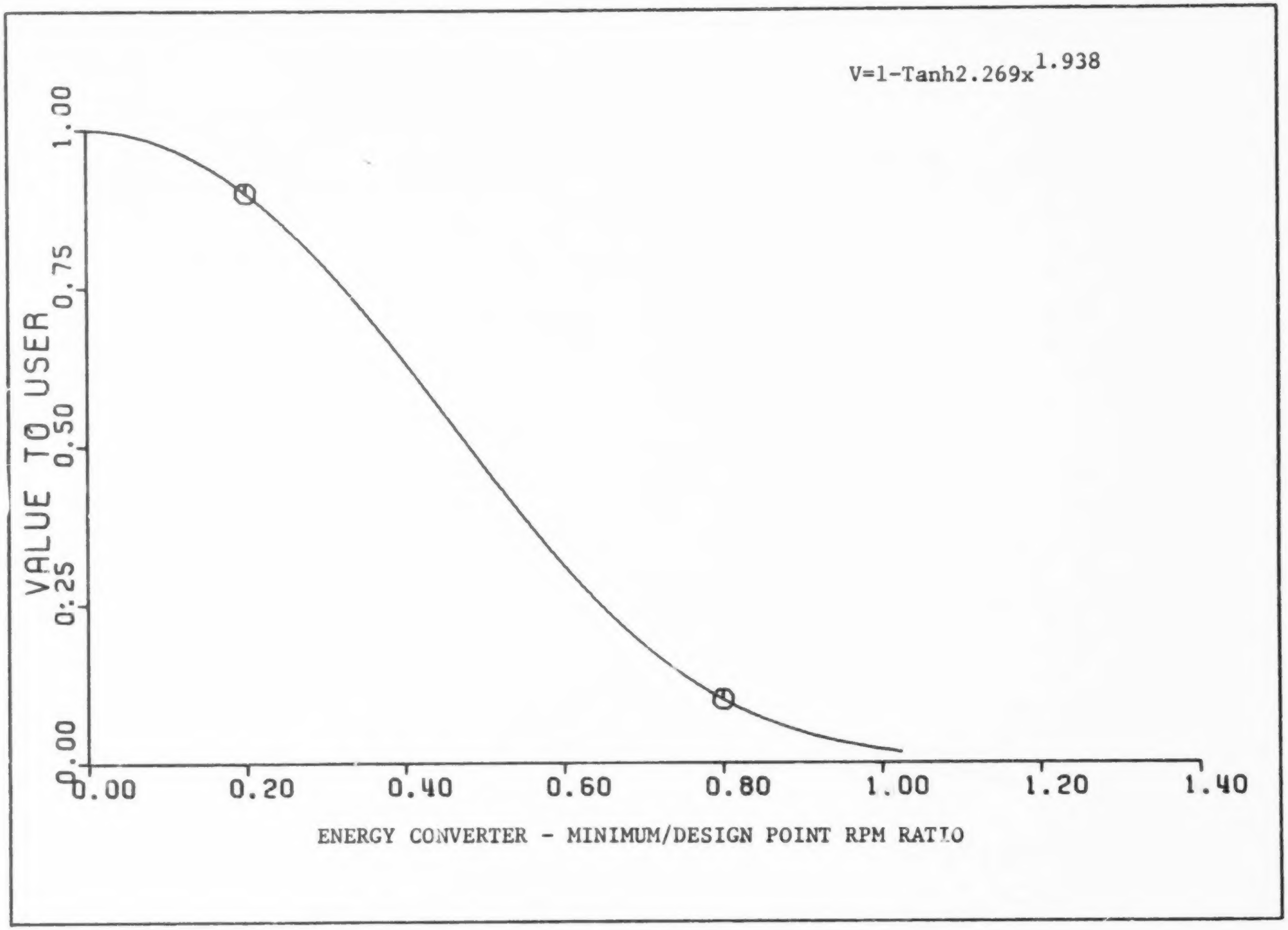
CURVE

7.11

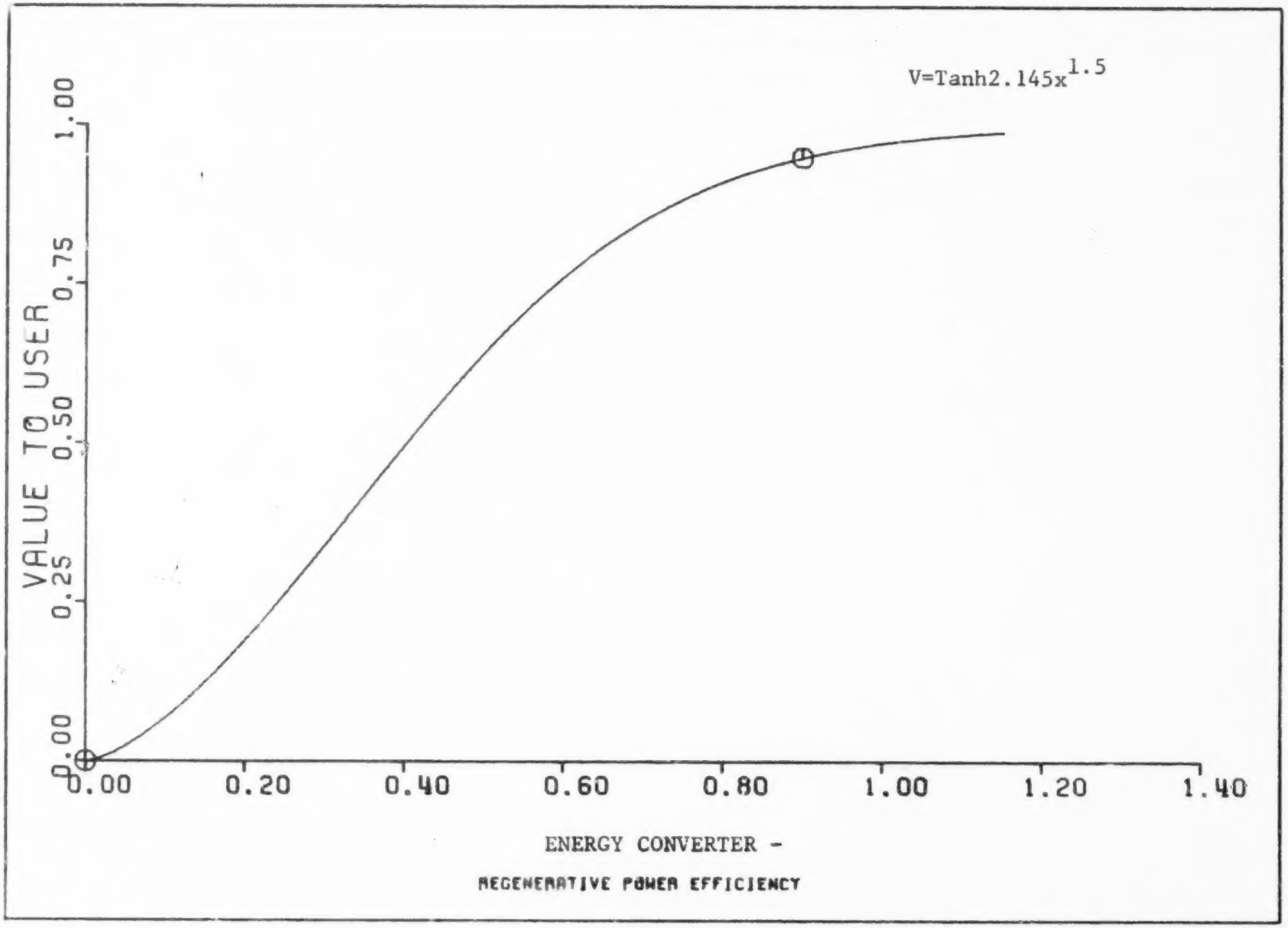

V=Tanh.2456x$^{1.292}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.80
1.60
2.40
3.20
4.00
4.80
5.60
ENERGY CONVERTER - STALL/DESIGN POINT TORQUE RATIO

CURVE

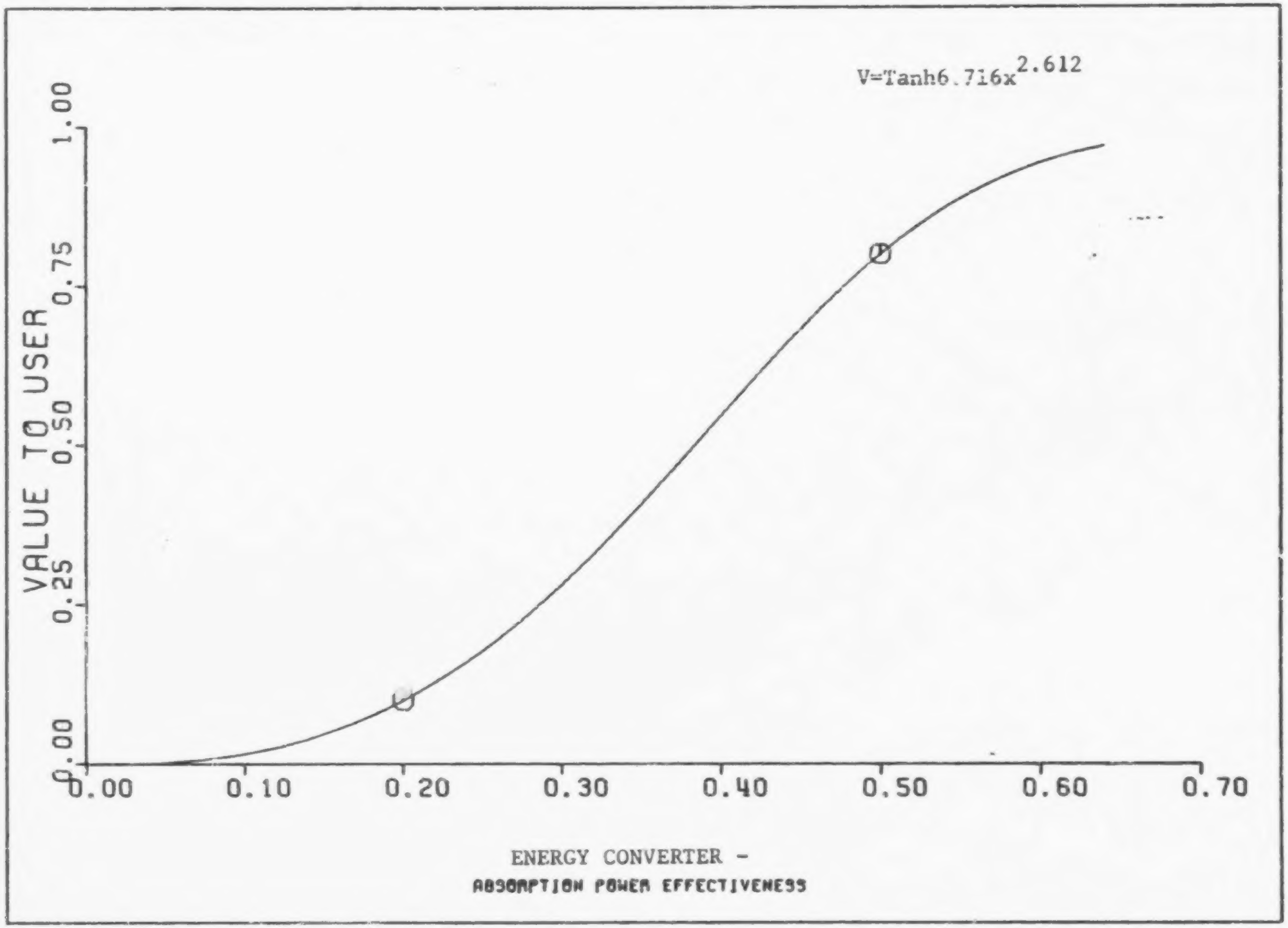
7.12


V=1-Tanh2.269x$^{1.938}$
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
ENERGY CONVERTER - MINIMUM/DESIGN POINT RPM RATIO

CURVE
7.13

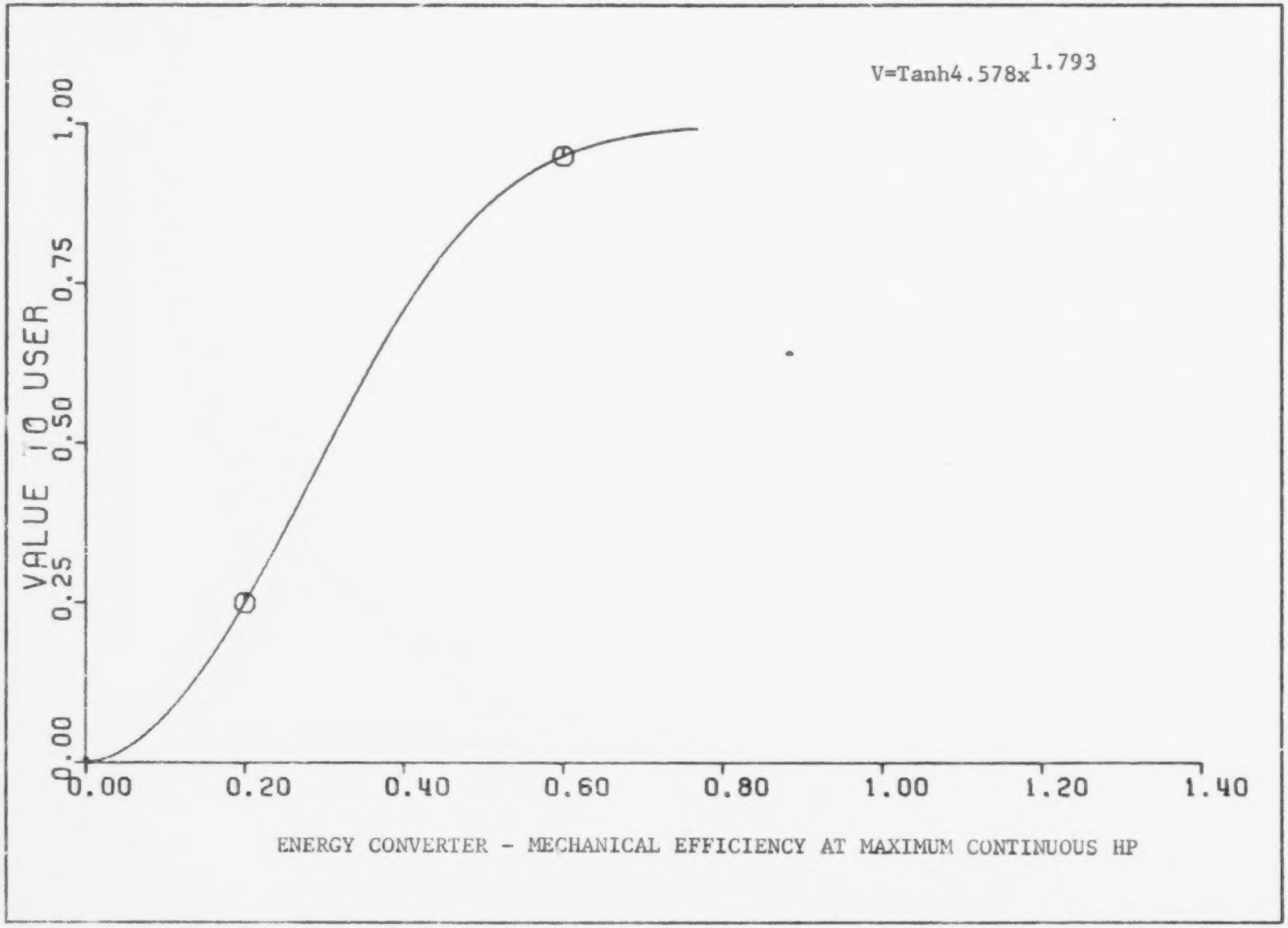

V=Tanh2.145x^1.5
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
ENERGY CONVERTER -
REGENERATIVE POWER EFFICIENCY

CURVE
7.14

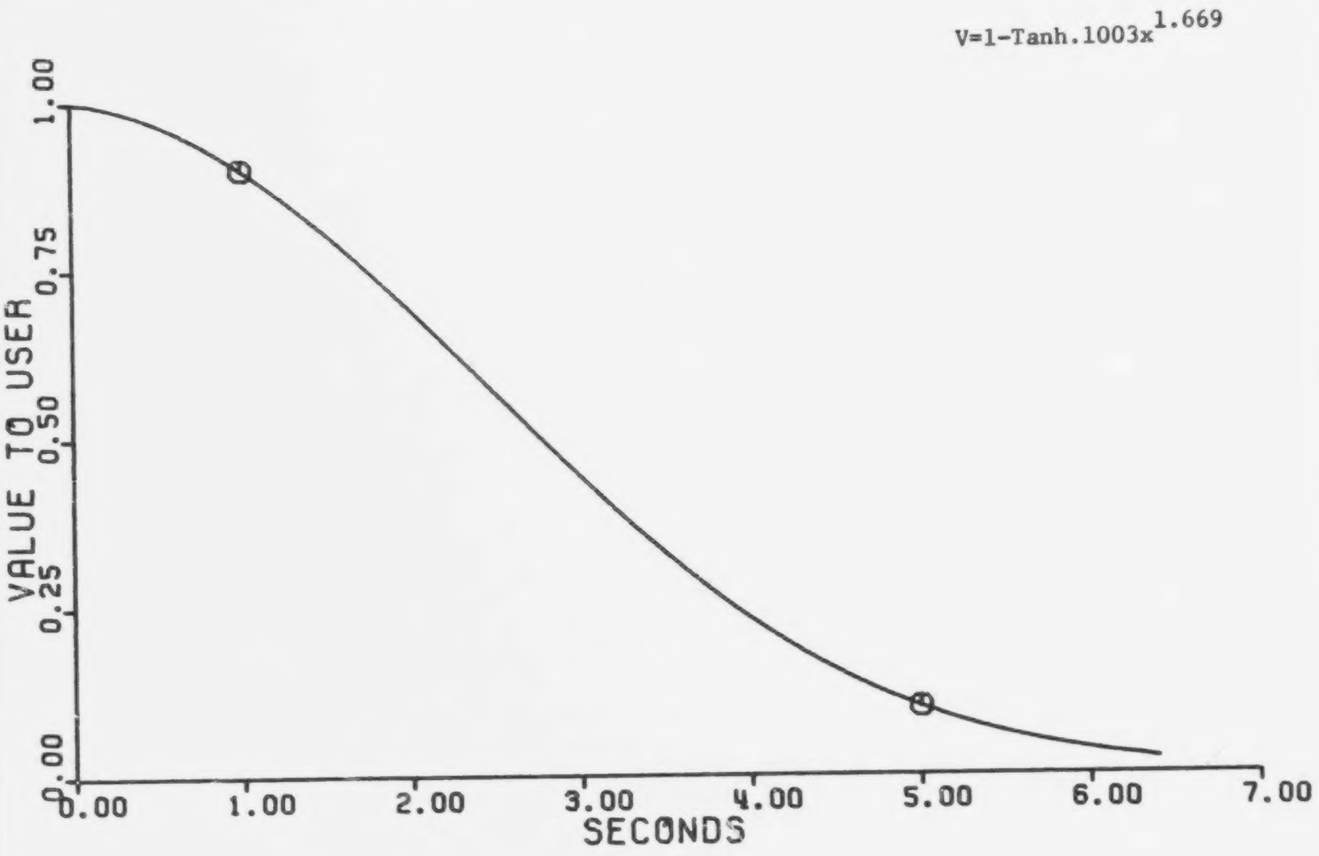

V=Tanh6.716x$^{2.612}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
ENERGY CONVERTER -
ABSORPTION POWER EFFECTIVENESS

CURVE

7.15


V=Tanh4.578x$^{1.793}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
ENERGY CONVERTER - MECHANICAL EFFICIENCY AT MAXIMUM CONTINUOUS HP

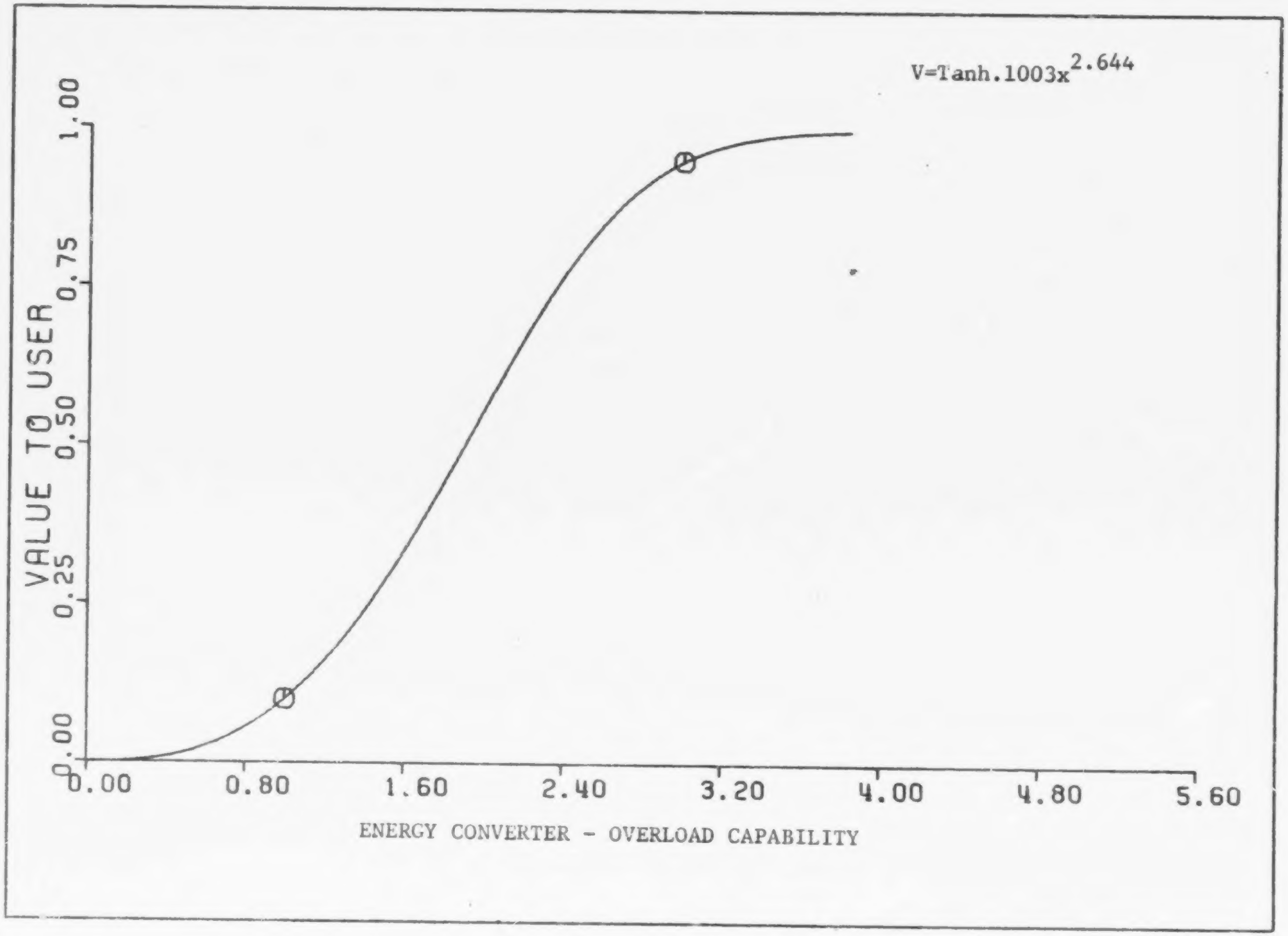
CURVE
7.16



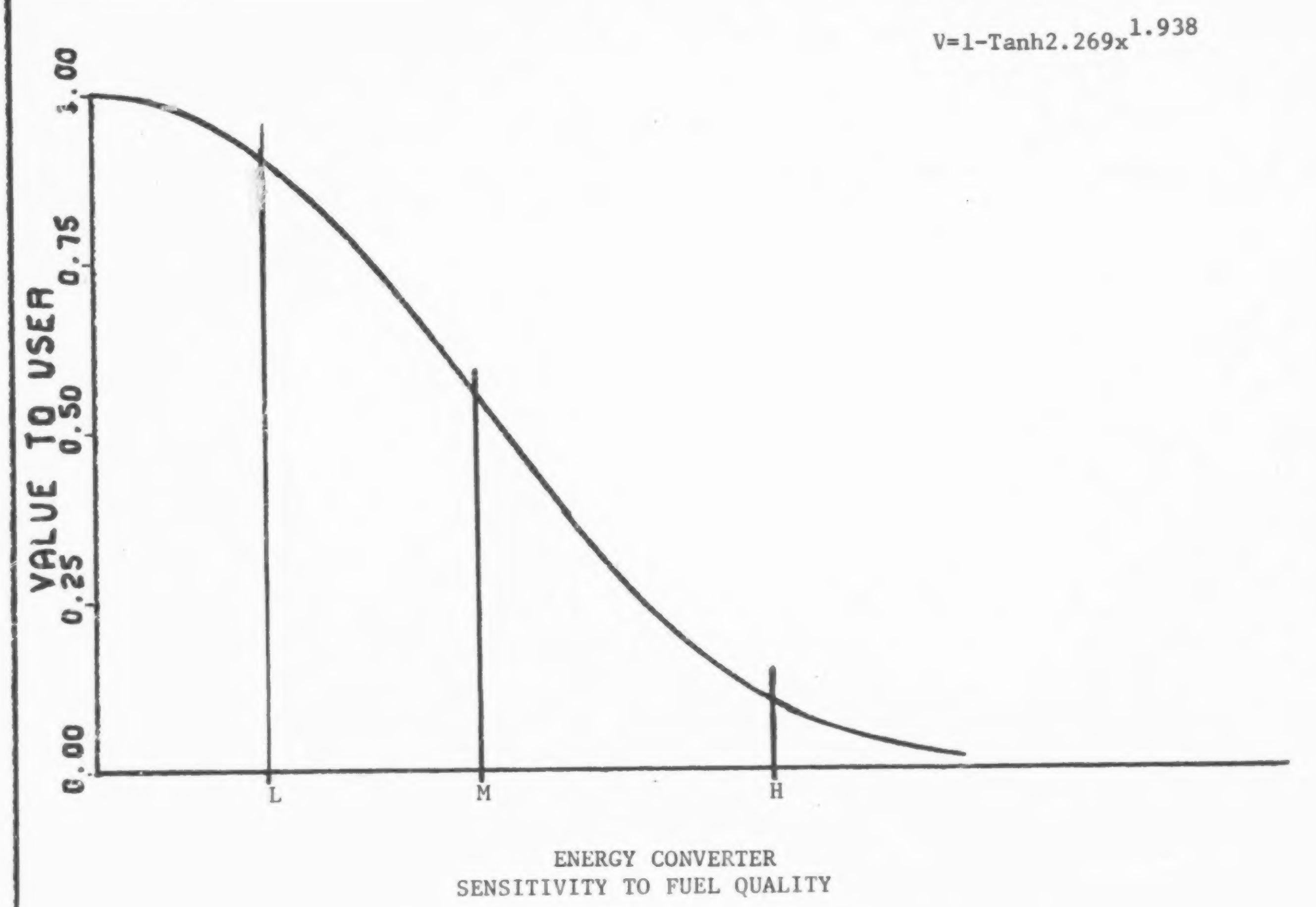
ENERGY CONVERTER - RESPONSE TO LOAD CHANGE

CURVE

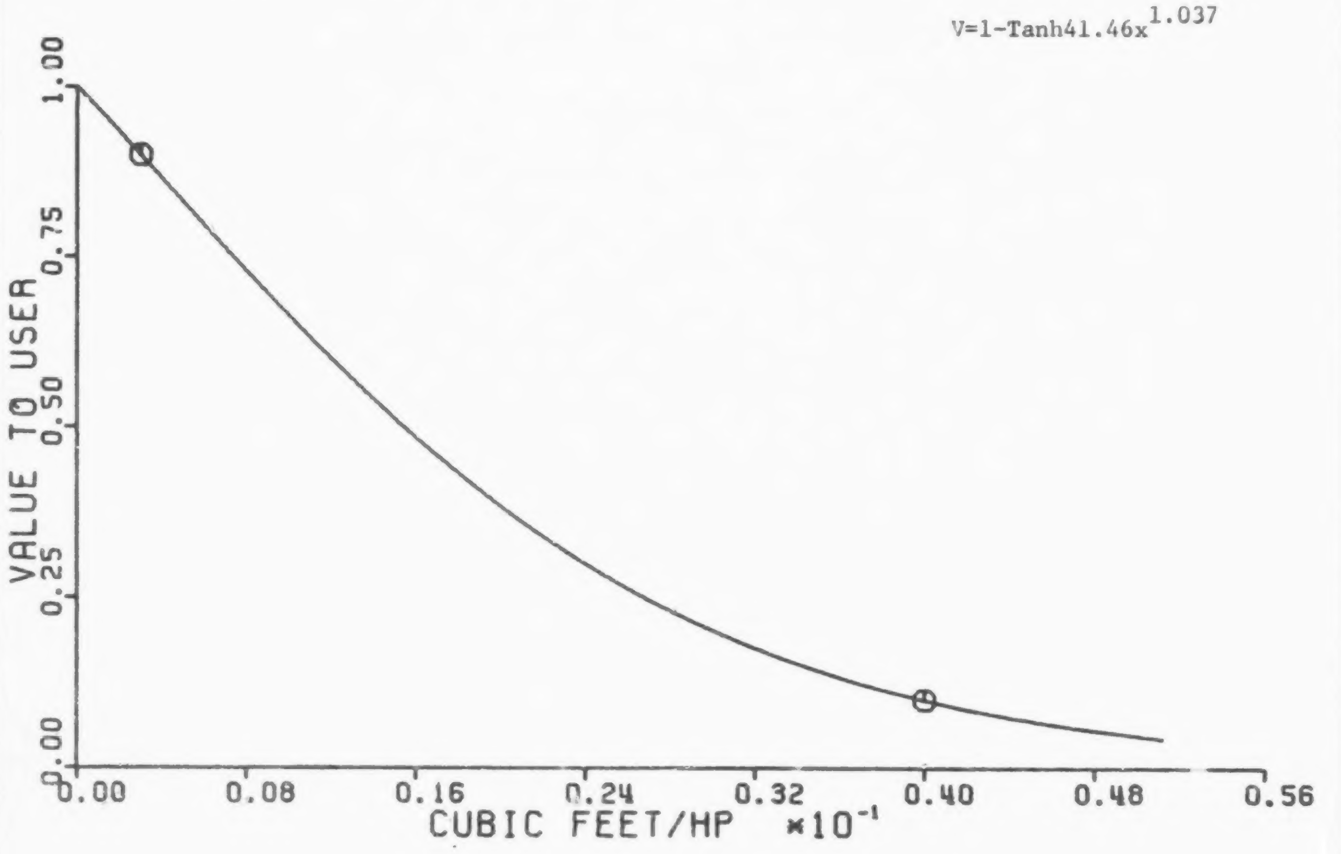
7.17


V=Tanh.1003x$^{2.644}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.80
1.60
2.40
3.20
4.00
4.80
5.60
ENERGY CONVERTER - OVERLOAD CAPABILITY

CURVE
7.18


V=1-Tanh2.269x^1.938
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
L
M
H
ENERGY CONVERTER
SENSITIVITY TO FUEL QUALITY

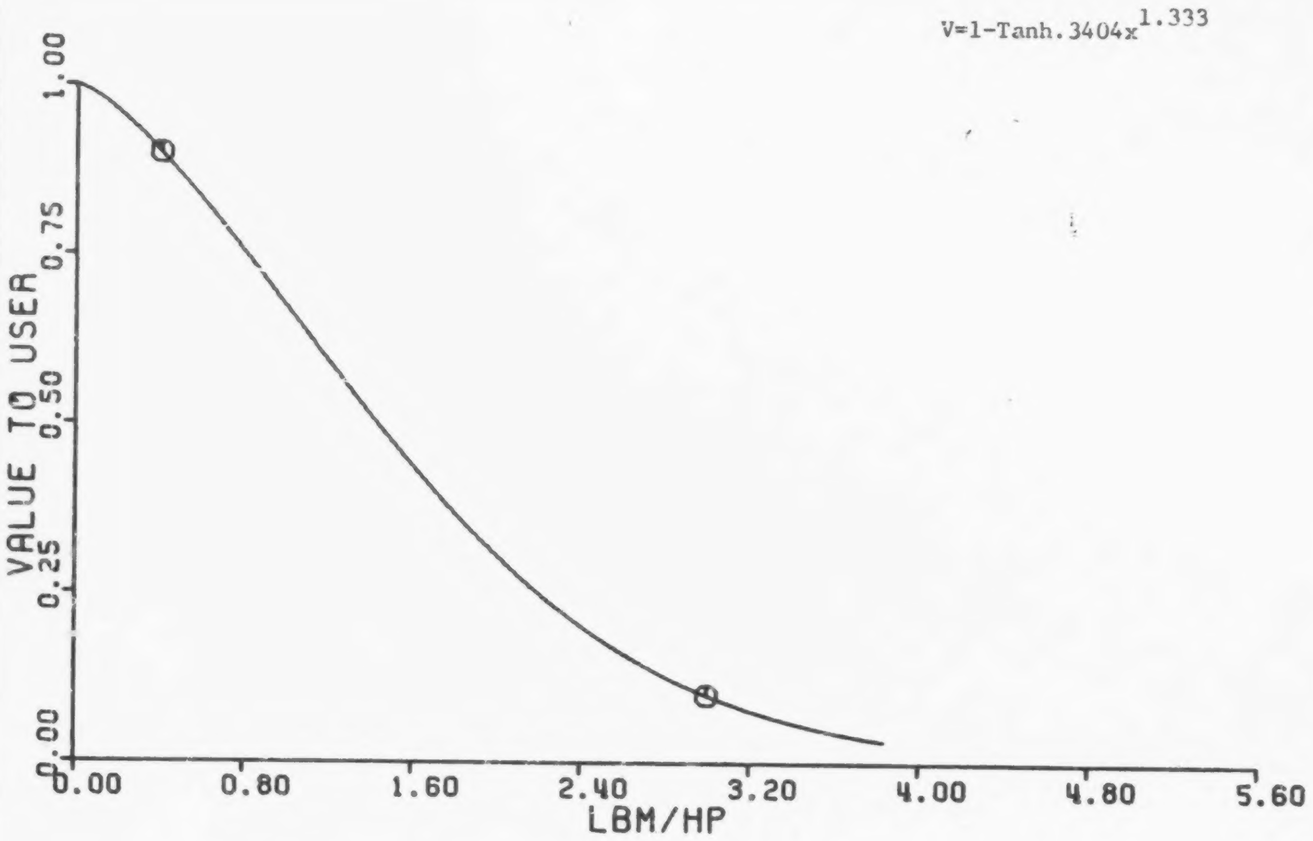
CURVE
7.19



POWER CONDITIONER - SPECIFIC VOLUME

CURVE

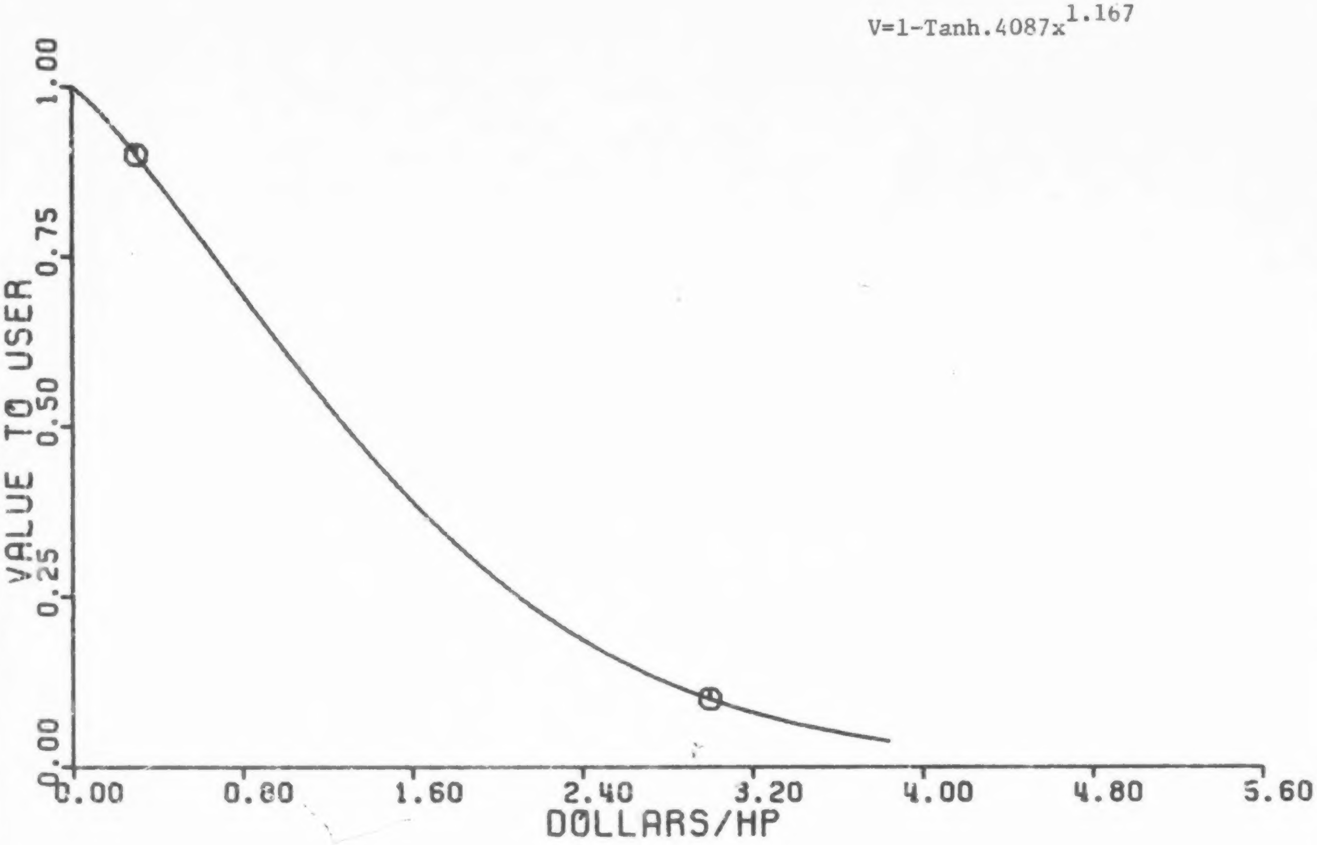
7.20



POWER CONDITIONER - SPECIFIC WEIGHT

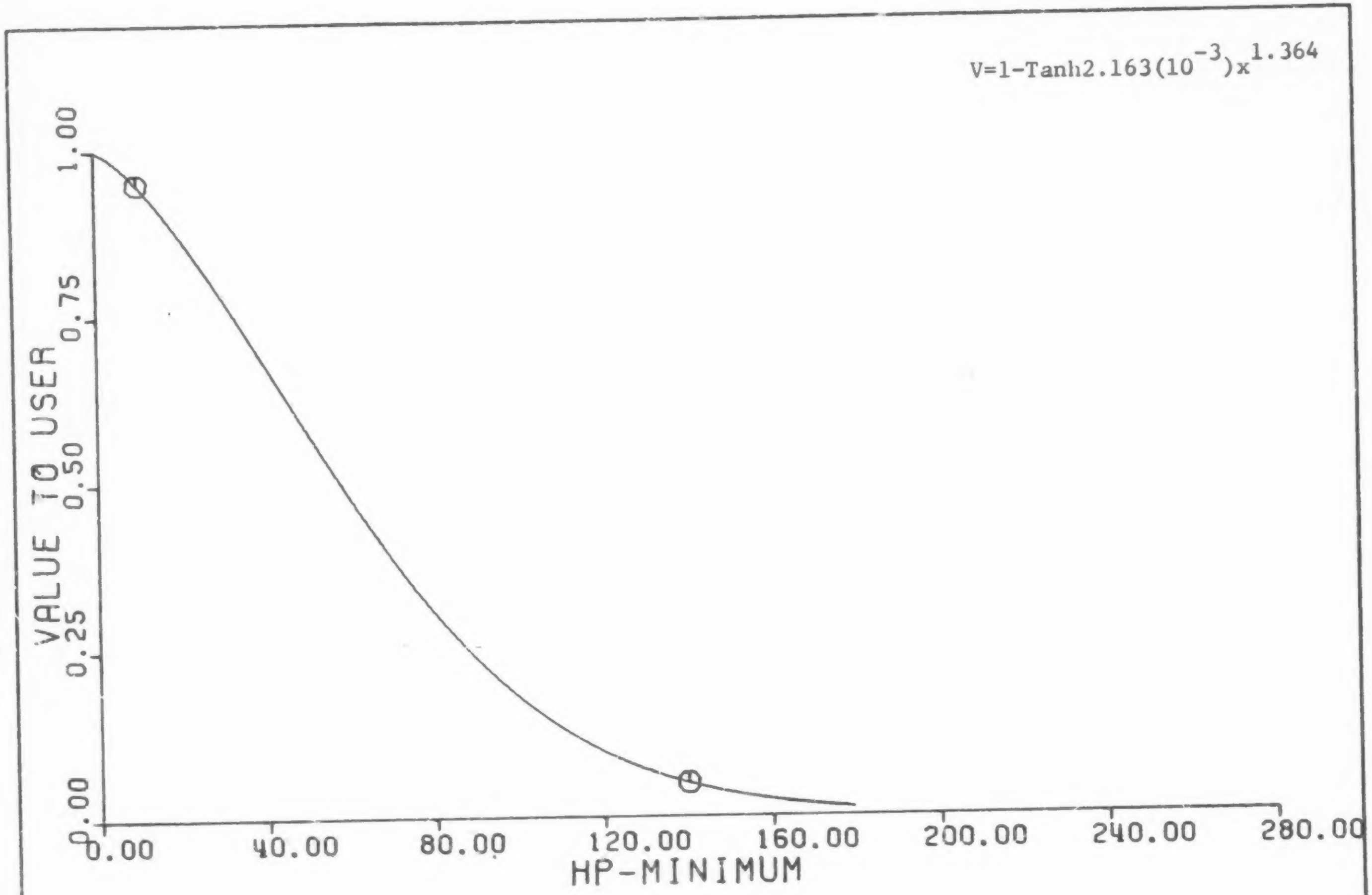
CURVE

7.21



POWER CONDITIONER - SPECIFIC COST

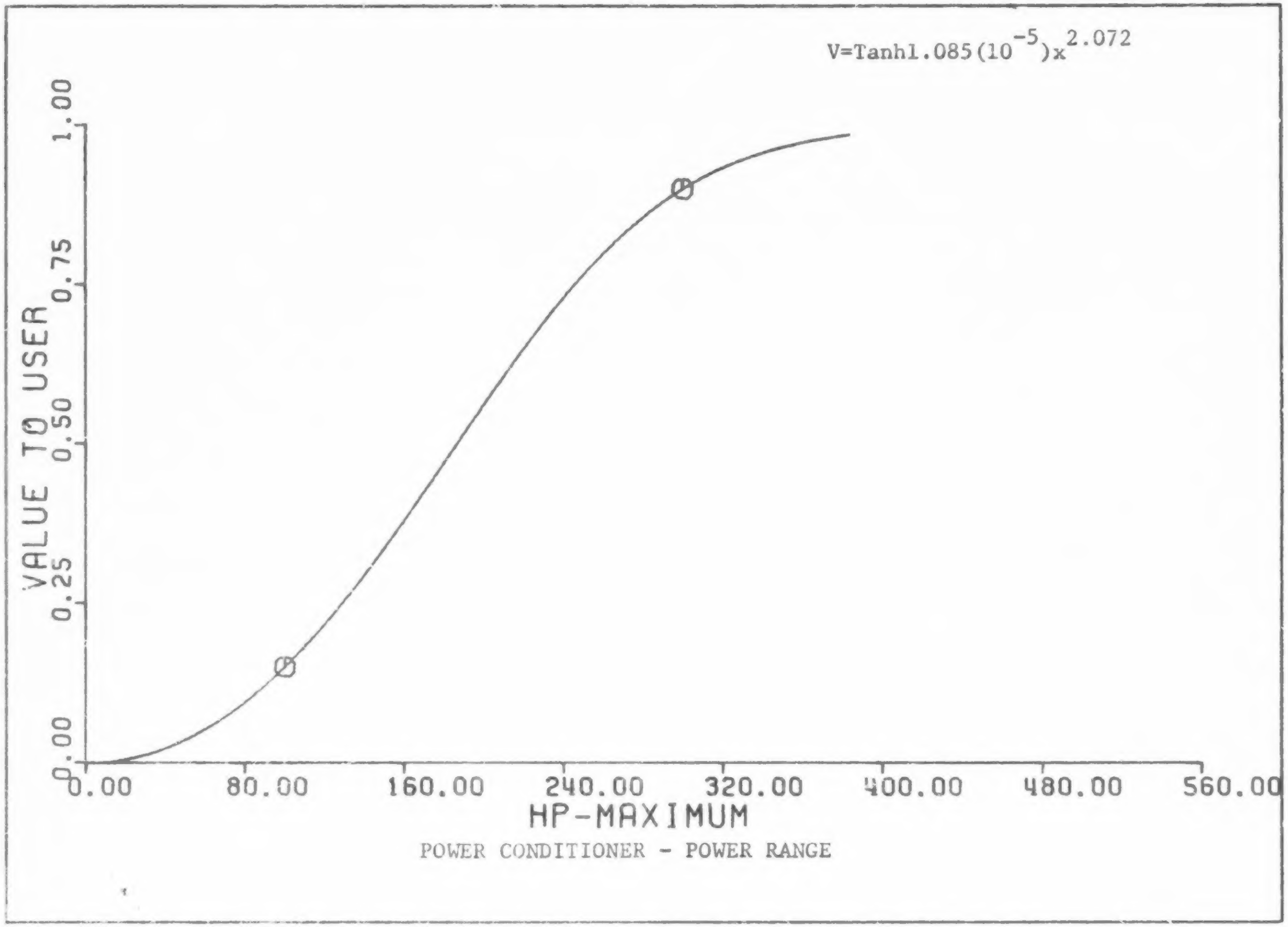
CURVE
7.22



POWER CONDITIONER - POWER RANGE

CURVE

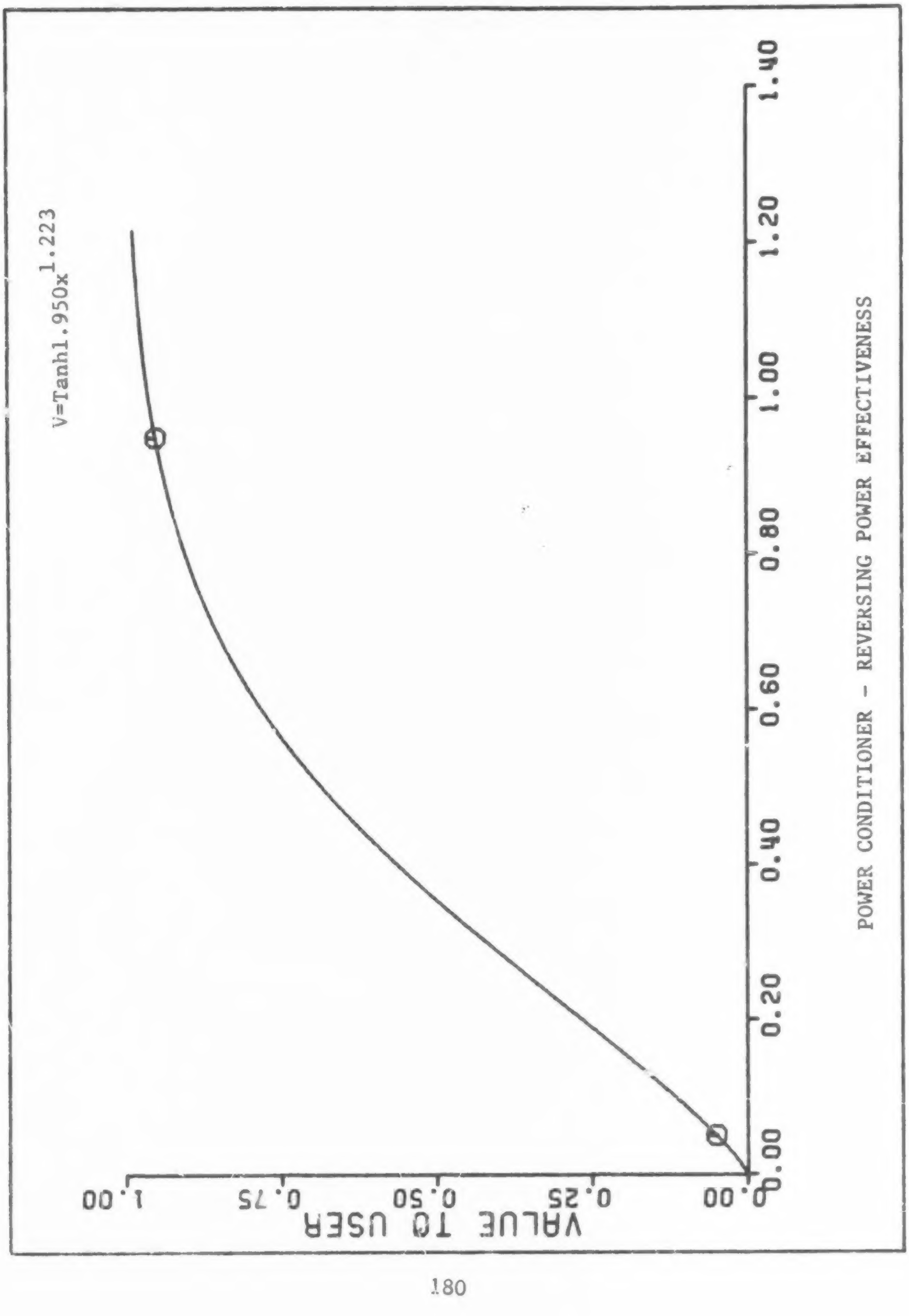
7.23



POWER CONDITIONER - POWER RANGE

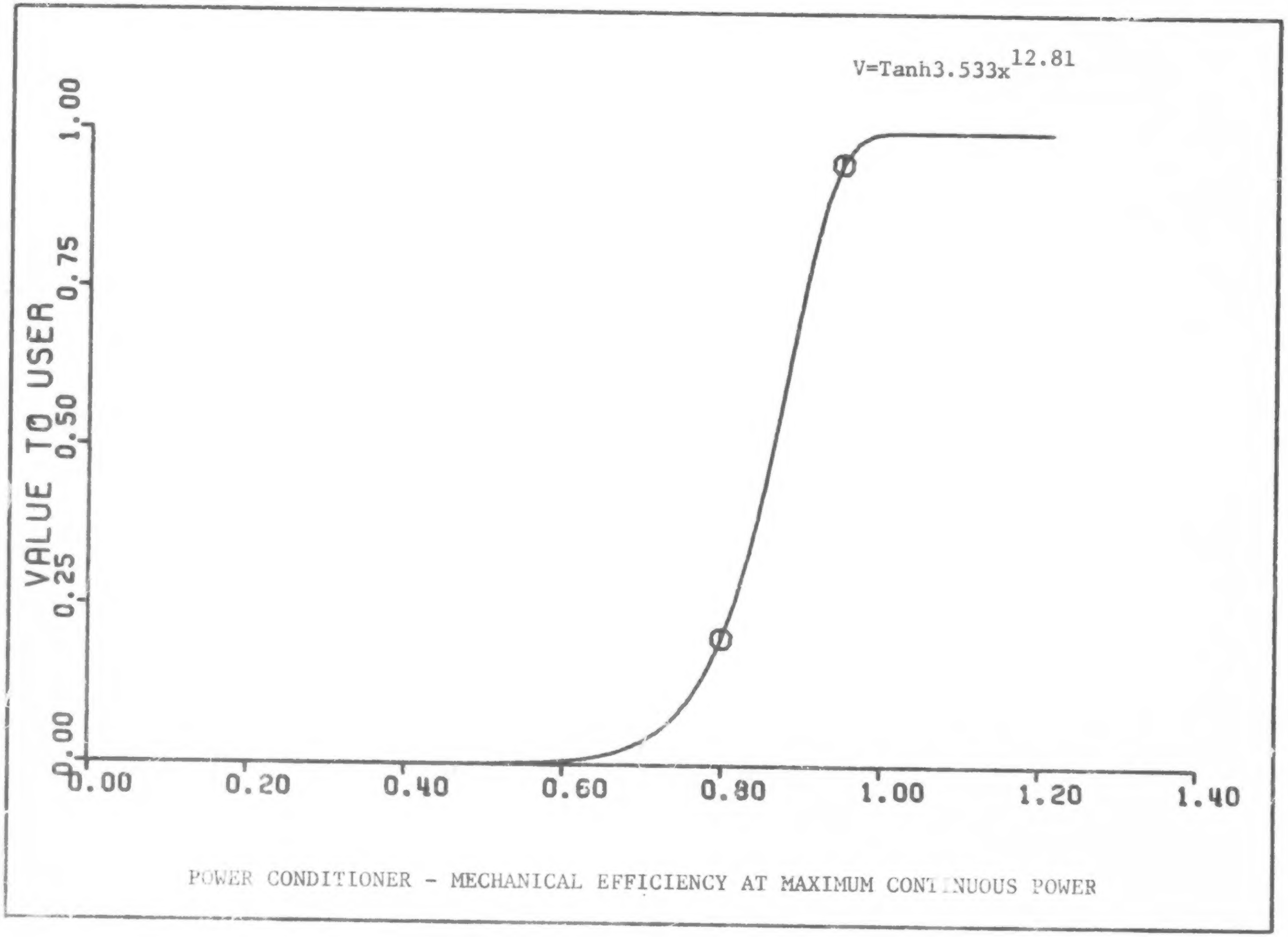
CURVE

7.24



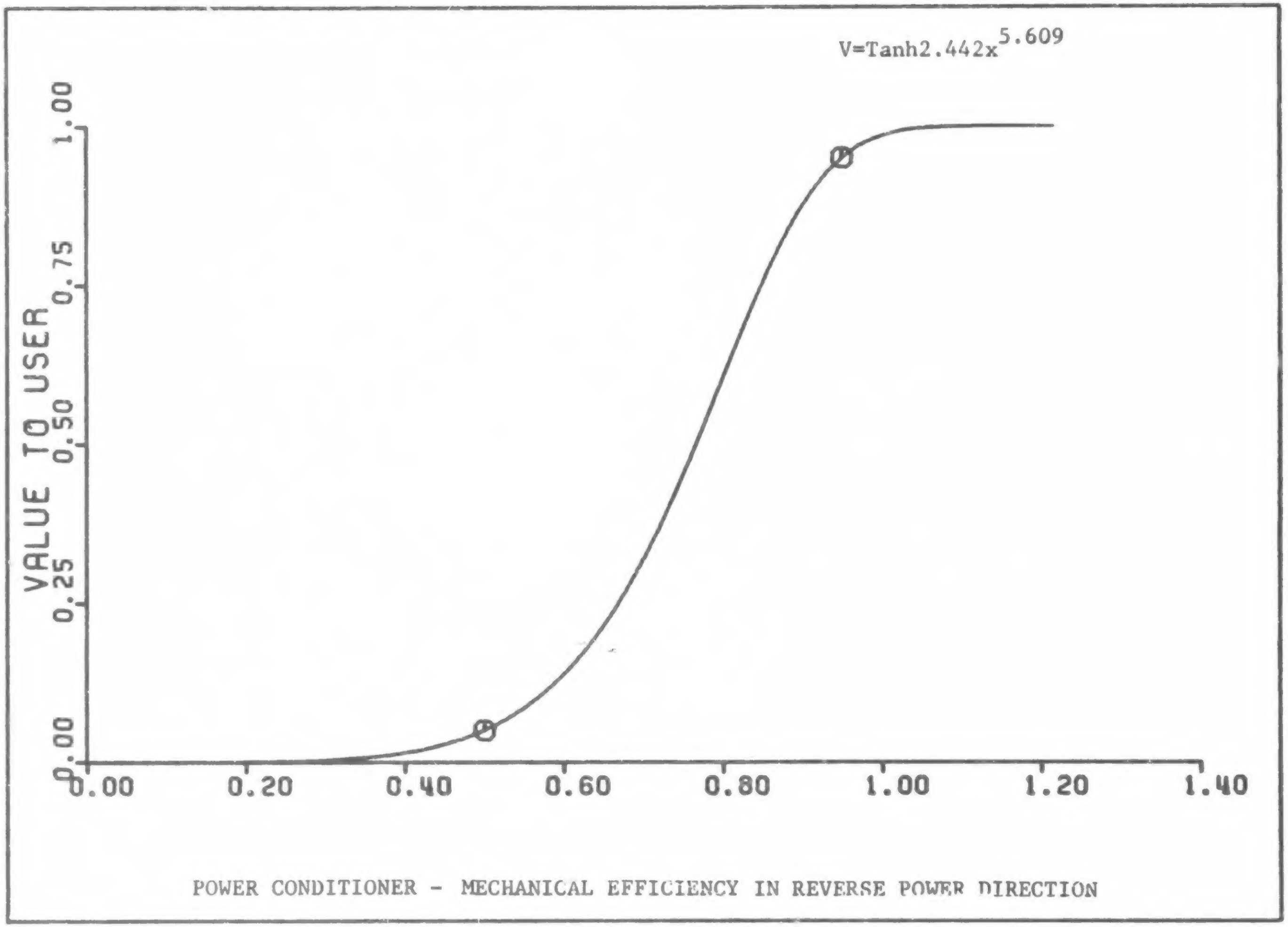
$V=\tanh 1.950x^{1.223}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
POWER CONDITIONER - REVERSING POWER EFFECTIVENESS

CURVE
7.25

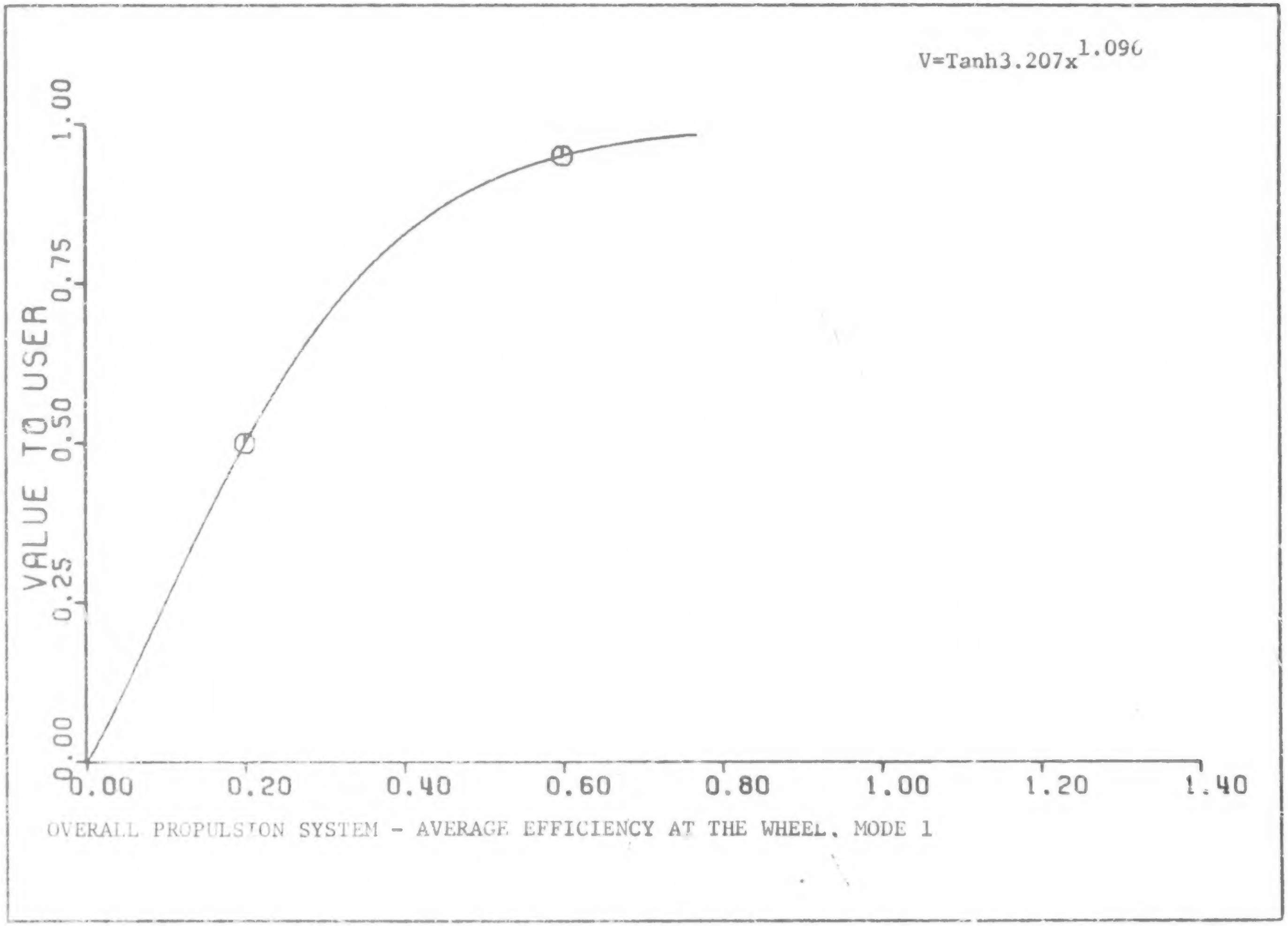

V=Tanh3.533x^12.81
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
POWER CONDITIONER - MECHANICAL EFFICIENCY AT MAXIMUM CONTINUOUS POWER

CURVE

7.26

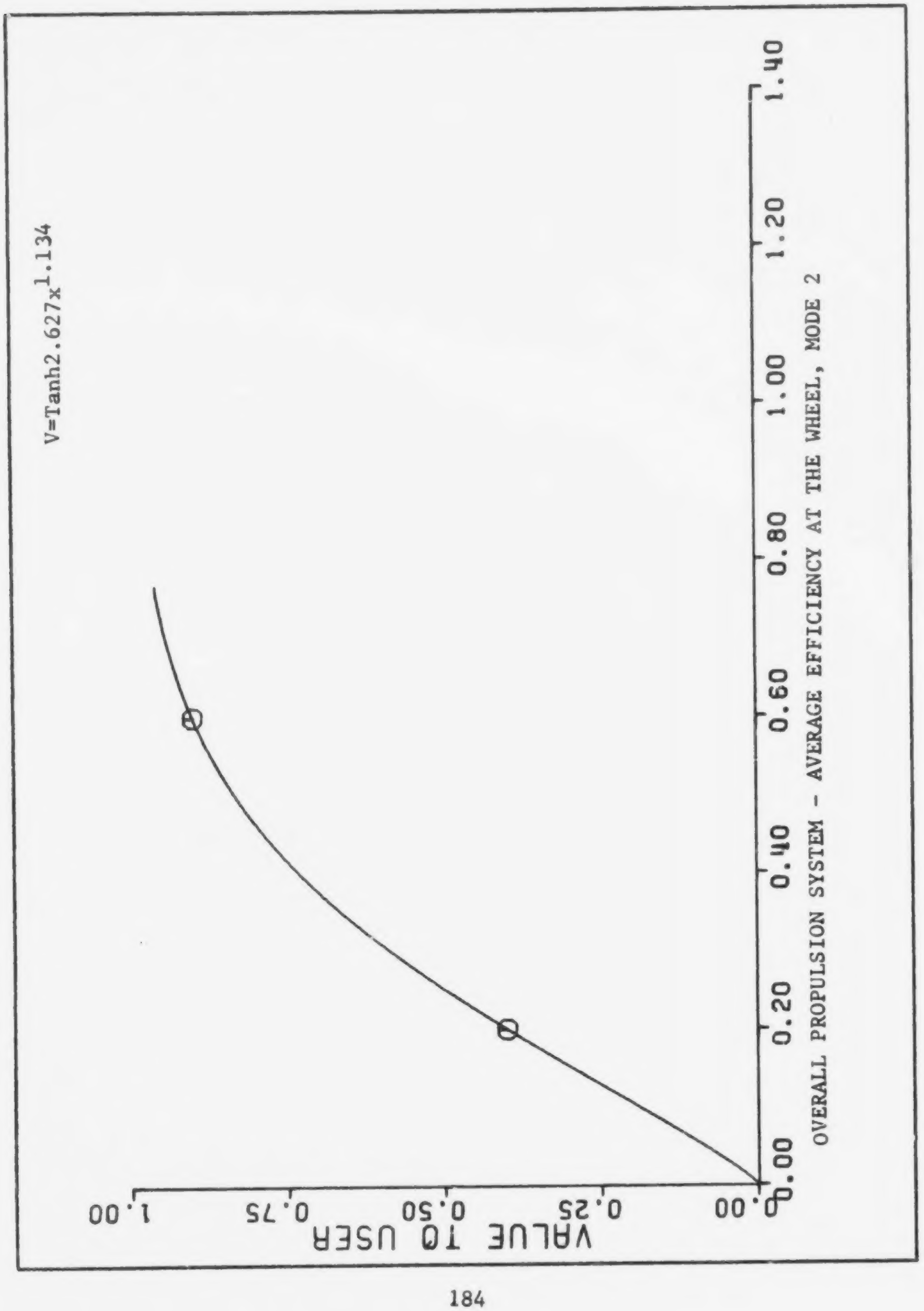

V=Tanh2.442x$^{5.609}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
POWER CONDITIONER - MECHANICAL EFFICIENCY IN REVERSE POWER DIRECTION

CURVE
7.27

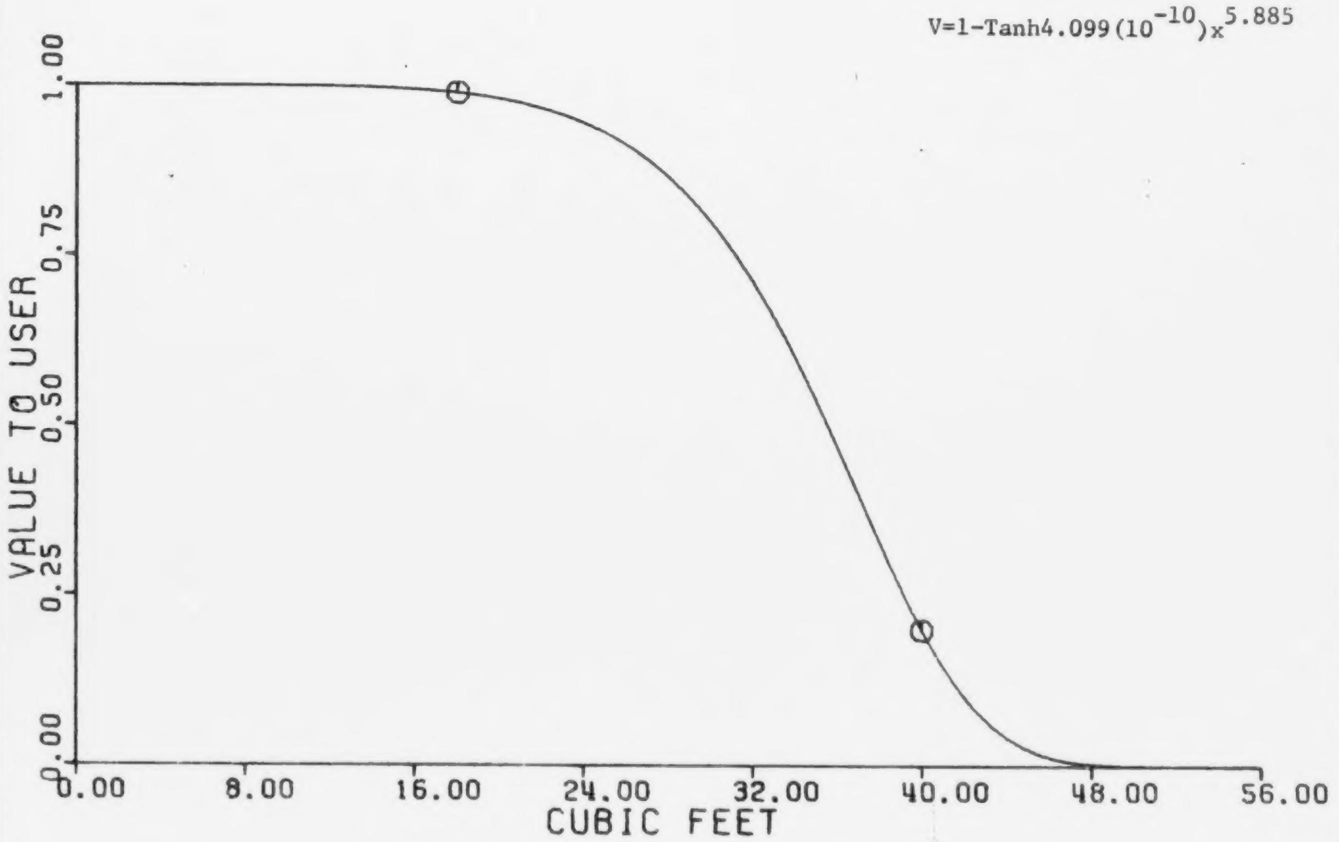

V=Tanh3.207x^1.096
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
OVERALL PROPULSION SYSTEM - AVERAGE EFFICIENCY AT THE WHEEL, MODE 1

CURVE

7.28


V=Tanh2.627x^1.134
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
OVERALL PROPULSION SYSTEM - AVERAGE EFFICIENCY AT THE WHEEL, MODE 2

CURVE
7.29

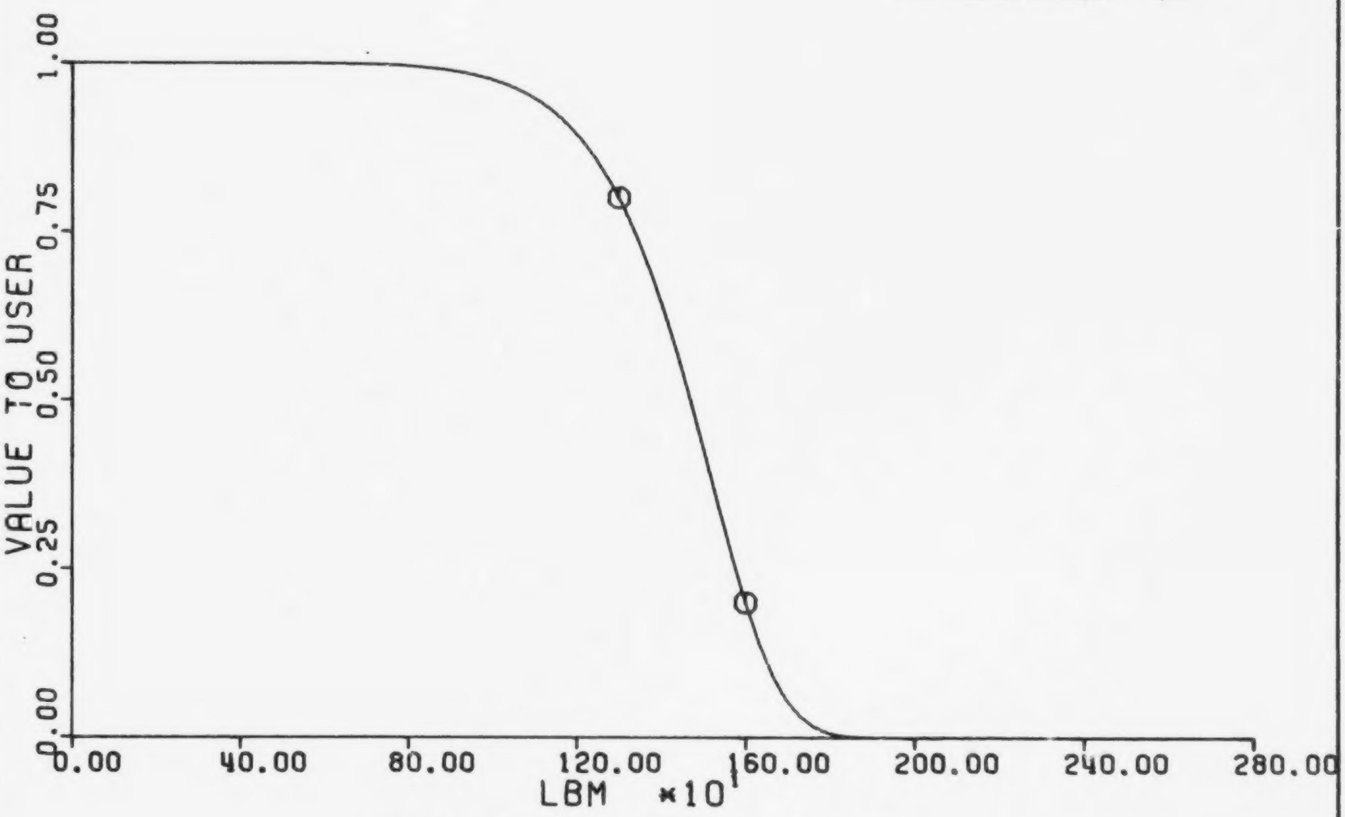


OVERALL PROPULSION SYSTEM - TOTAL VOLUME

CURVE

7.30

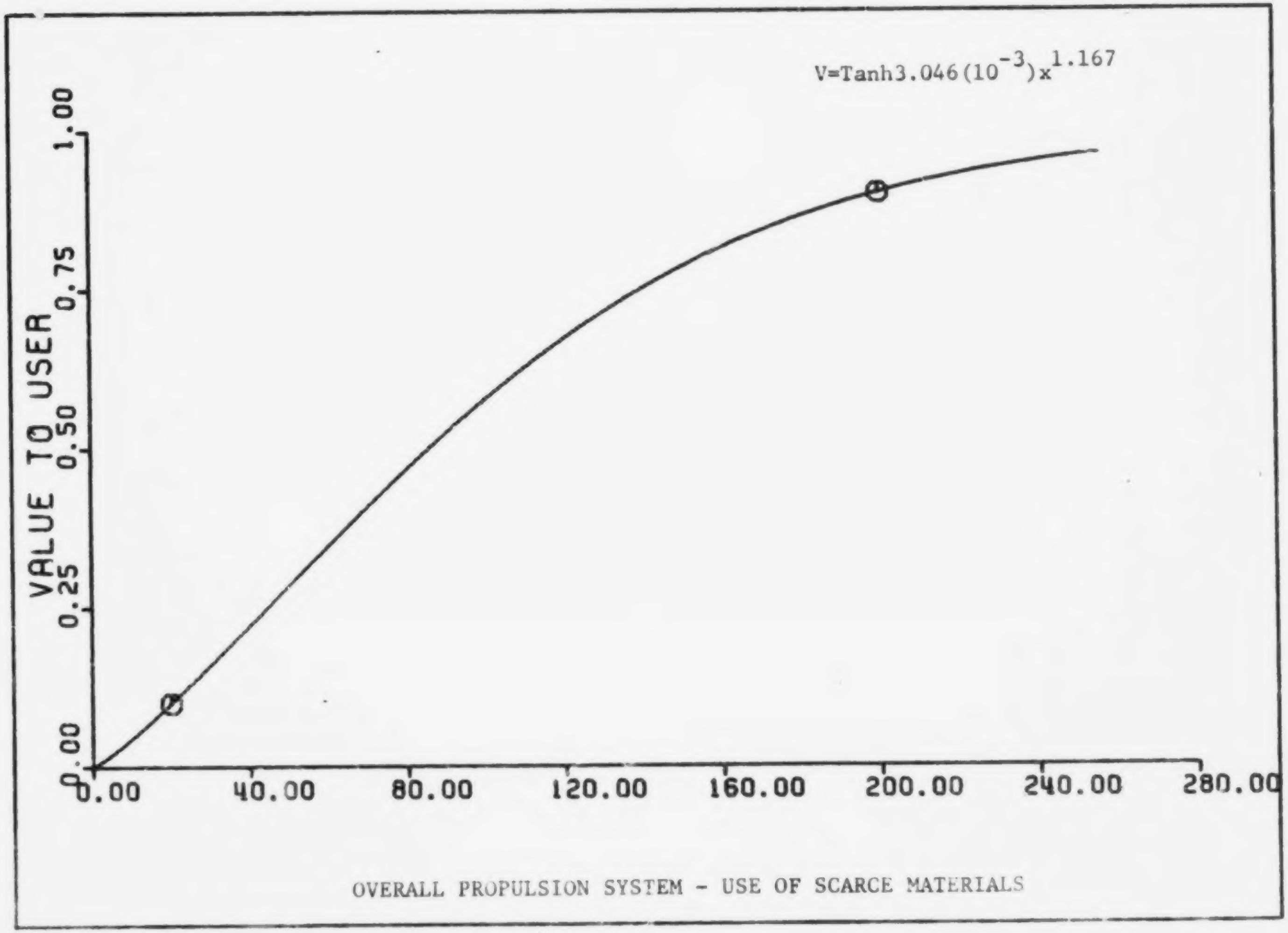
$V=1-\tanh 9.193(10^{-27})x^{8.139}$



OVERALL PROPULSION SYSTEM - TOTAL WEIGHT

CURVE

7.31

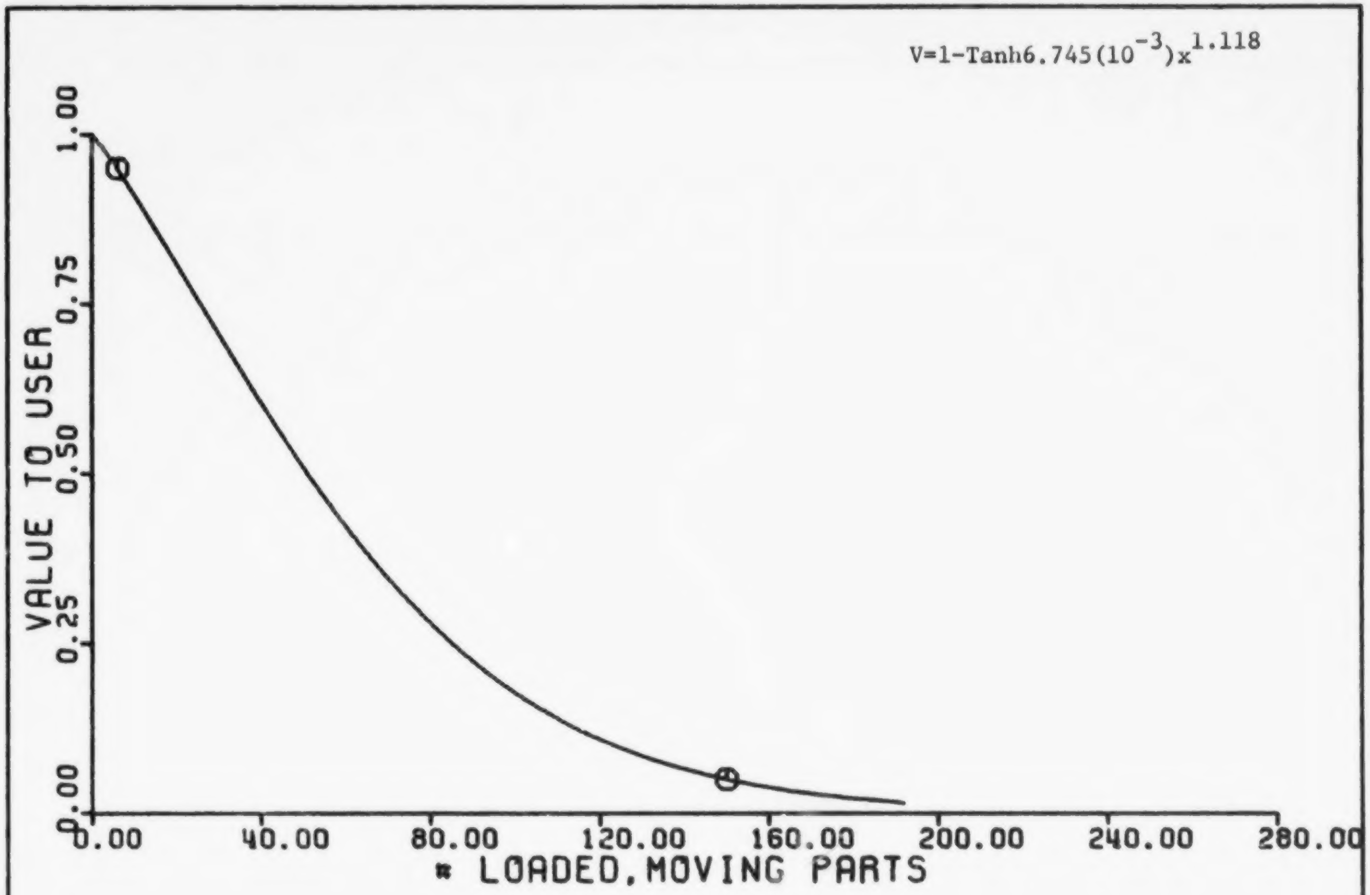

V=Tanh3.046(10^{-3})x$^{1.167}$
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
OVERALL PROPULSION SYSTEM - USE OF SCARCE MATERIALS

CURVE

7.32

4.1.9 Reliability and Maintenance

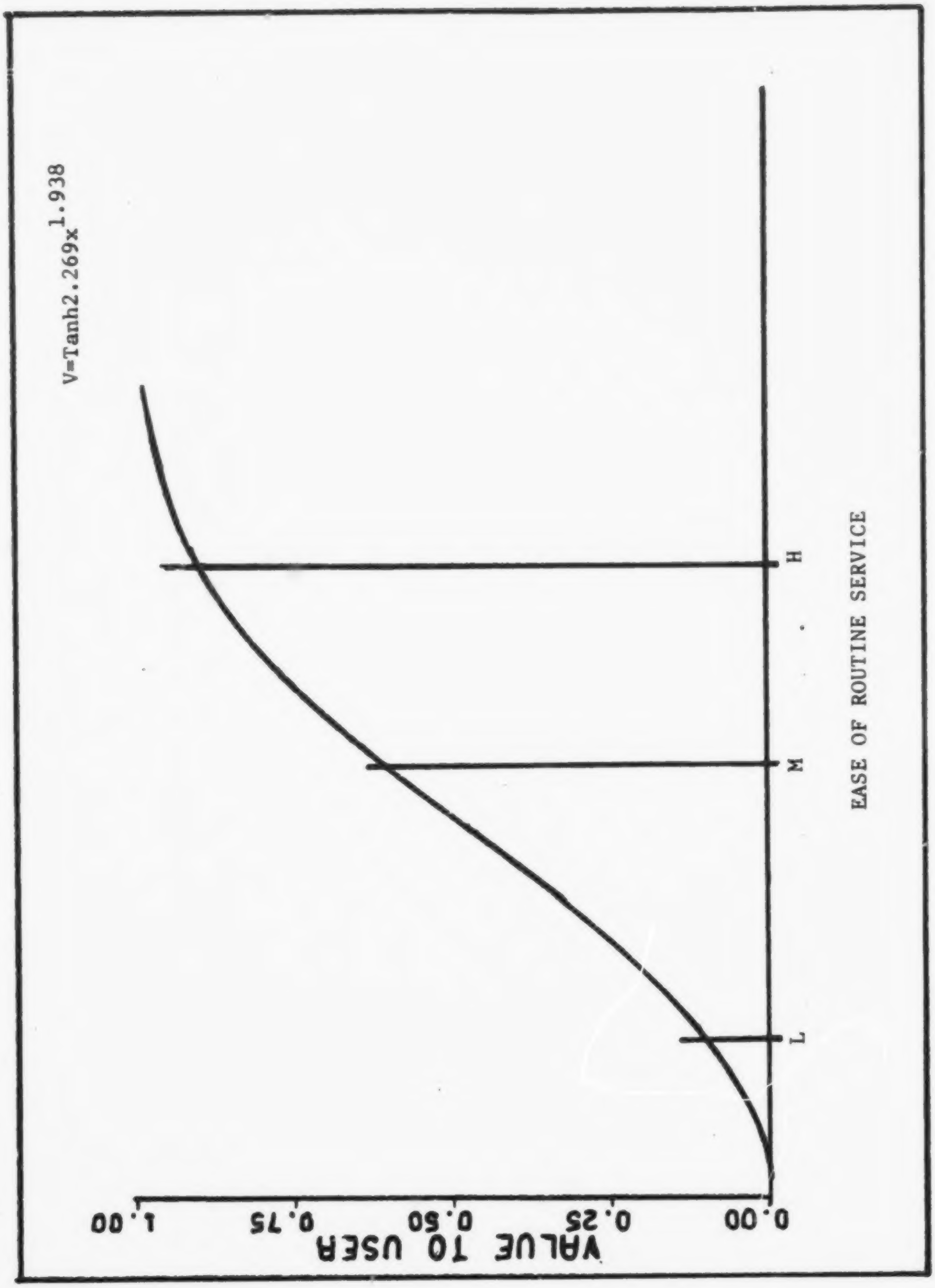
Complexity of System - Curve 8.1
Ease of Routine Service - Curve 8.2
Expense of Unscheduled Repairs - Curve 8.3
Design Life - Curve 8.4
Period Between Routine Servicing - Curve 8.5
Estimated Mean Miles Between Failures - Curve 8.6



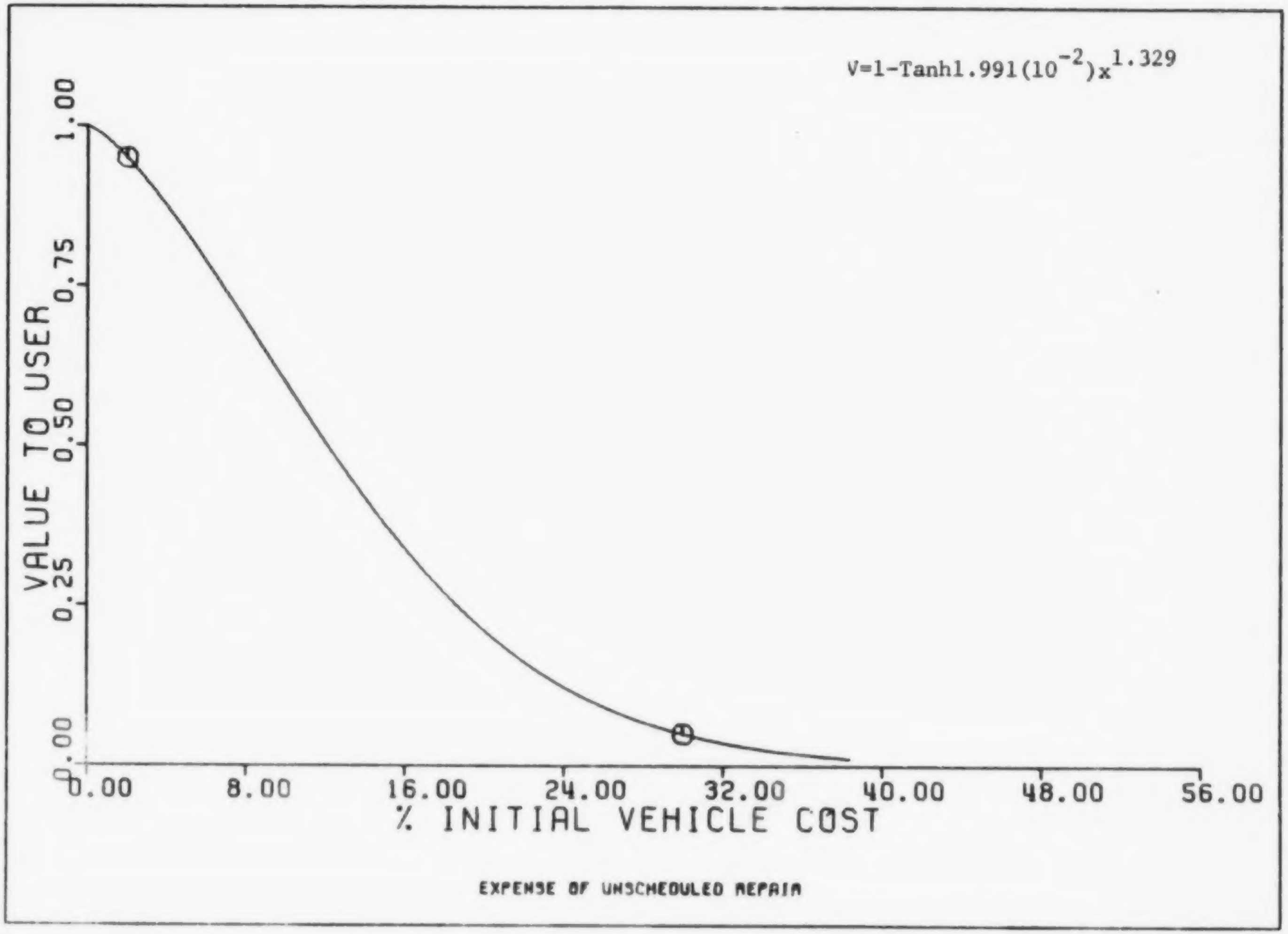
COMPLEXITY OF SYSTEM

CURVE

8.1

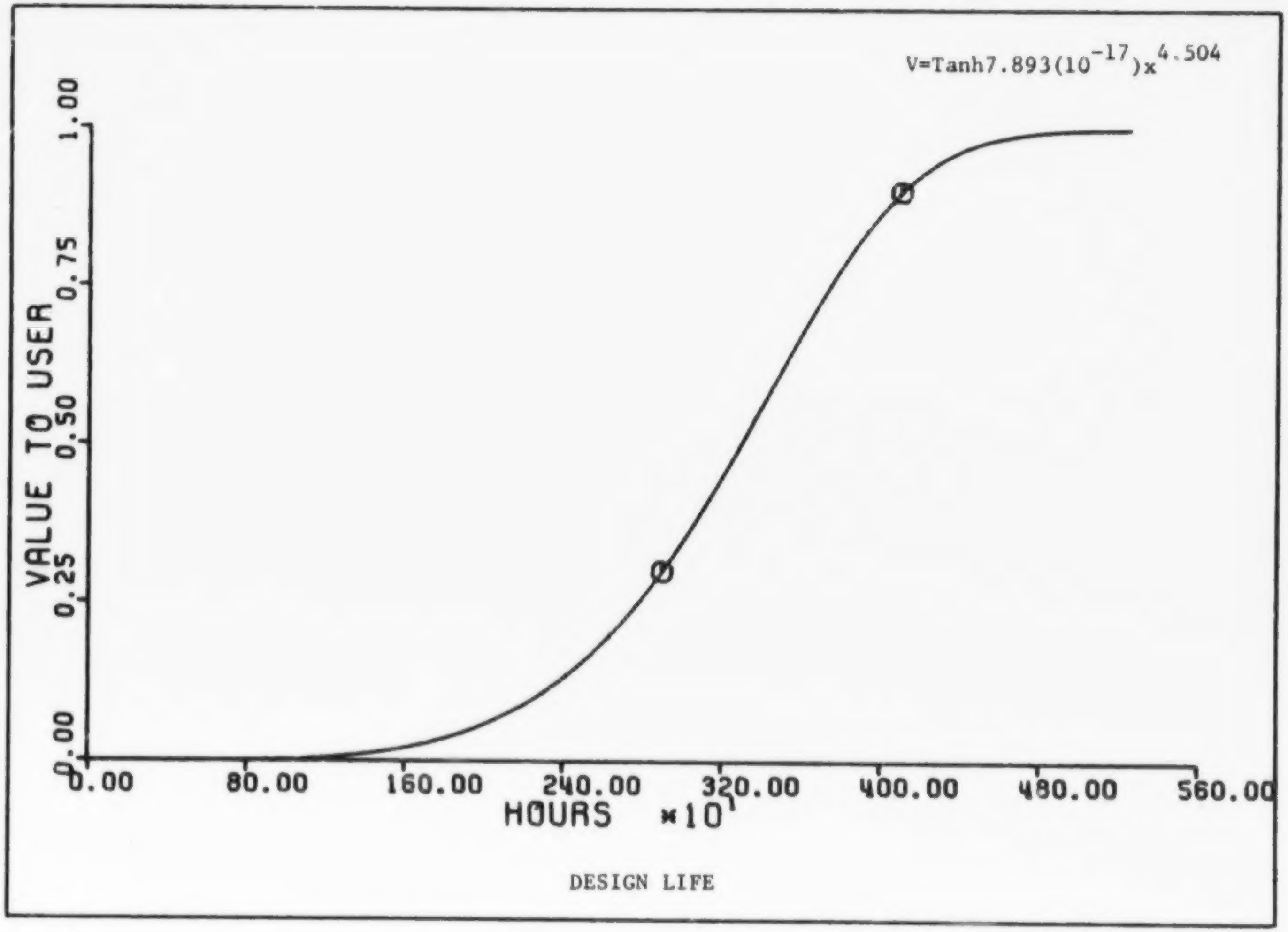

V=Tanh2.269x^1.938
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
L
M
H
EASE OF ROUTINE SERVICE

CURVE
8.2


V=1-Tanh1.991(10^-2)x^1.329
VALUE TO USER
1.00
0.75
0.50
0.25
0.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
% INITIAL VEHICLE COST
EXPENSE OF UNSCHEDULED REPAIR

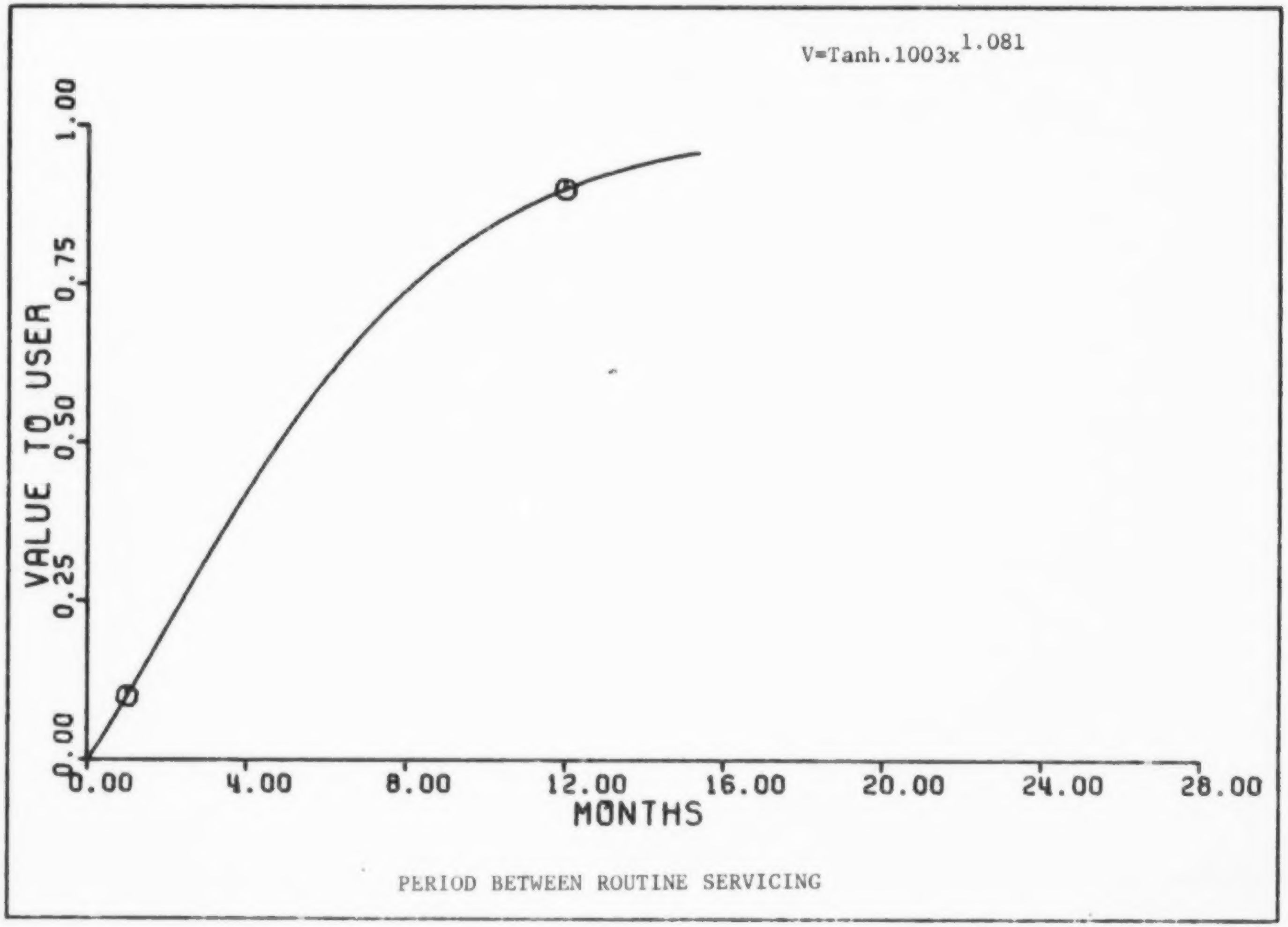
CURVE

8.3


V=Tanh7.893(10^-17)x^4.504
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
HOURS *10^1
DESIGN LIFE

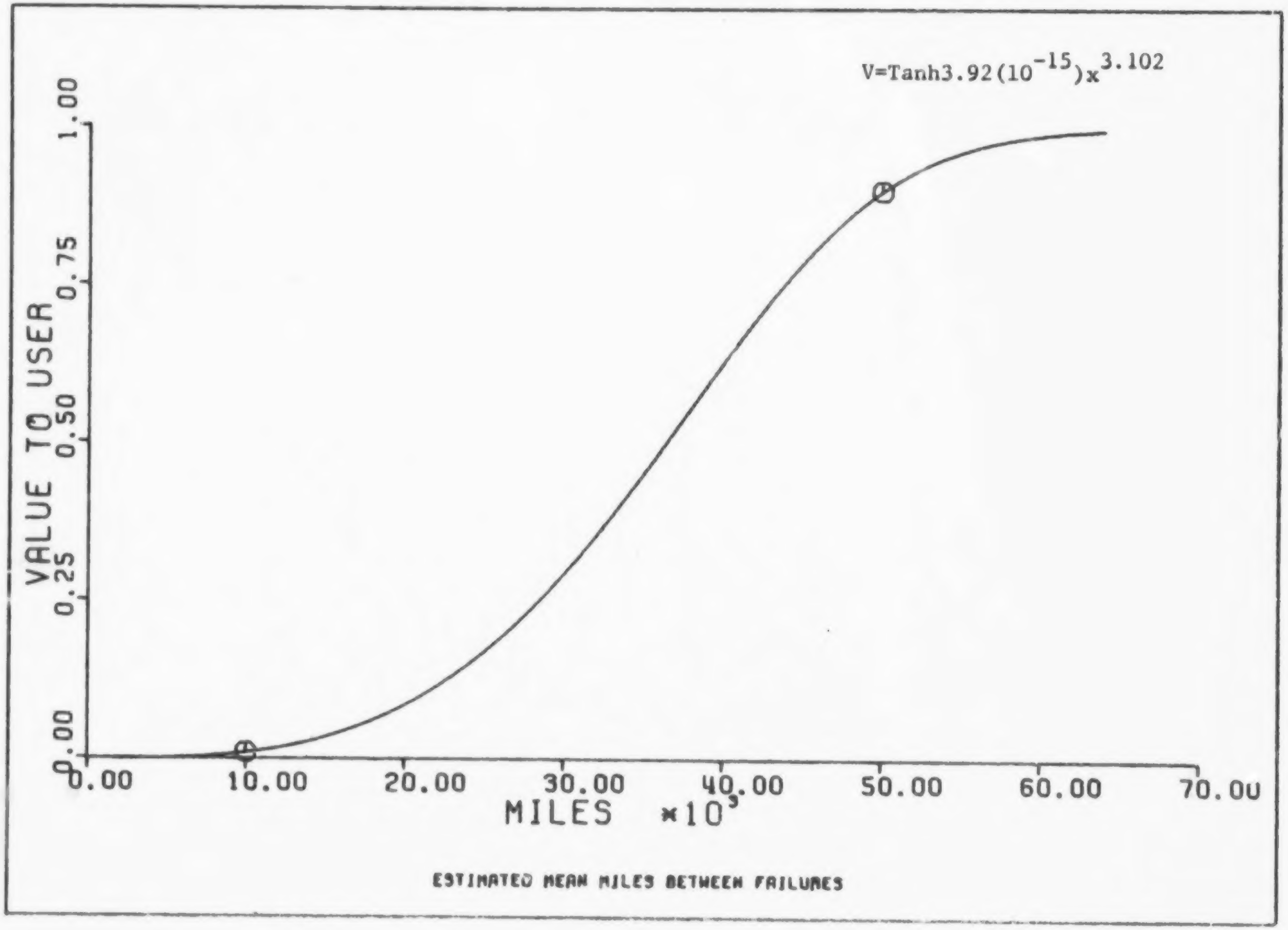
CURVE

8.4


V=Tanh.1003x^1.081
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MONTHS
PERIOD BETWEEN ROUTINE SERVICING

CURVE

8.5


V=Tanh3.92(10^-15)x^3.102
VALUE TO USER
0.00
0.25
0.50
0.75
1.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
MILES ×10^3
ESTIMATED MEAN MILES BETWEEN FAILURES

CURVE

8.6

4.2 Category Value Sets

The category value set establishes the relationship among the parameter value functions within a particular category. A parameter value function may either be expressed as a term or a factor in the value set: a term being related to other category parameters by an additive relationship and a factor being related to other category parameters by a multiplicative relationship. Each parameter designated a term is also given a weight which establishes the relative importance of the term. The sum of these weights is equal to one.

The general equation for the category value set is:

$$V_c = \prod_{j=1}^{n} F_j (X_j) \sum_{i=1}^{m} A_i F_i (X_i)$$

where

$$\sum_{i=1}^{m} A_i = 1$$

V_c = category value

A = weights assigned to terms

F = value function

X = parameter measurement value

i and j are indices.

The following value sets have been established for the eight evaluation categories. These value sets represent the consensus of DAAPSD and MITRE personnel.

4.2.1 Emission Value Set

The emission category value set is as follows:

$$V_E = [(V_{1.1})(V_{1.2})(V_{1.3})(V_{1.4})(V_{1.5})] \; [.2(V_{1.6})+.2(V_{1.7}) + .12(V_{1.8}) + .14(V_{1.9}) + .2(V_{1.10}) + .14(V_{1.11})]$$

The value functions and value judgment curves for the category parameters $V_{1.1}$ through $V_{1.11}$ are found in Section 4.1.2.

4.2.2 Operating Performance Value Set

The operating performance category value set is as follows:

$$V_{OP} = .06V_{2.1} + .05V_{2.2} + .06V_{2.3} + .06V_{2.4} + .04V_{2.5} + .05V_{2.6} + .07V_{2.7} + .1V_{2.8} + .09V_{2.9} + .1V_{2.10} + .05V_{2.11} + .07V_{2.12} + .09V_{2.13} + .11V_{2.14}$$

The value functions and value judgment curves for the category parameters $V_{2.1}$ through $V_{2.14}$ are found in Section 4.1.3.

4.2.3 Acceptability Value Set

The acceptability category value set is as follows:

$$V_A = .25\, V_{3.1} + .15V_{3.2} + .20V_{3.3} + .16V_{3.4} + .12\, V_{3.5} + .12\, V_{3.6}$$

The value functions and value judgment curves for the category parameters $V_{3.1}$ thorugh $V_{3.6}$ are found in Section 4.1.4.

4.2.4 Operating Environment Value Set

The operating environment category value set is as follows:

$$V_{OE} = (V_{4.1})(V_{4.2})(V_{4.4})\ [.3V_{4.3} + .4V_{4.5} + .15V_{4.6} + .15V_{4.7}]$$

The value functions and value judgment curves for the category parameters $V_{4.1}$ through $V_{4.7}$ are found in Section 4.1.5.

4.2.5 Safety Value Set

The safety category value set is as follows:

$$V_S = (V_{5.1})(V_{5.2})(V_{5.3})(V_{5.4})(V_{5.5})(V_{5.6})$$

The value functions and value judgment curves for the parameters $V_{5.1}$ through $V_{5.6}$ are found in Section 4.1.6.

4.2.6 Personnel and Facilities Value Set

The personnel and facilities category value set is as follows:

$$V_{PF} = .2V_{6.1} + .1V_{6.2} + .1V_{6.3} + .1V_{6.4} + .1V_{6.5} + .1V_{6.6} + .06V_{6.7} + .1V_{6.8} + .09V_{6.9} + .05V_{6.10}$$

The value functions and value judgment curves for parameters $V_{6.1}$ through $V_{6.10}$ are found in Section 4.1.7.

4.2.7 Propulsion System Technical Parameters Value Set

Due to the large number of parameters involved in the evaluation of propulsion system technology, the value set was sub-divided into five parts as follows:

$$V_{\text{Propulsion System}} = .3V_{\text{Resource Consumption}} + .2V_{\text{Volume and Weight}} + .2V_{\text{Fueling and Operating Convenience}} + .2V_{\text{Simplicity of Design}} + .1V_{\text{Initial Cost}}$$

where:

$$.3V_{\text{Resource Consumption}} = V_{7.3}\left[.07(V_{7.16})(V_{7.26}) + .05\,(V_{7.28} + V_{7.29}) + .03(V_{7.14})(V_{7.25})(V_{7.27})\right] + .05(V_{7.5} + V_{7.32})$$

$$.2V_{\text{Volume and Weight}} = \left[.005(V_{7.1})(V_{7.16})(V_{7.26}) + .005(V_{7.7})(V_{7.26}) + .005(V_{7.20}) + .065V_{7.30} + .007(V_{7.2})(V_{7.16})(V_{7.26}) + .007(V_{7.8})(V_{7.26}) + .007(V_{7.21}) + .099V_{7.31}\right]$$

$$.2V_{\text{Fueling and Operating Convenience}} = \left[.05(V_{7.6} + V_{7.17} + V_{7.18} + V_{7.19})\right]$$

$$.2V_{\text{Simplicity of Design}} = \left[.025\,(V_{7.10} + V_{7.11} + V_{7.13} + V_{7.15} + V_{7.23} + V_{7.24}) + .05\,(V_{7.12})\right]$$

$$.1V_{\text{Initial Cost}} = \left[.04\,(V_{7.4})(V_{7.16})(V_{7.26}) + .03\,(V_{7.9})(V_{7.26}) + .03\,(V_{7.22})\right]$$

The value functions and value judgment curves for parameters $V_{7.1}$ through $V_{7.32}$ are found in Section 4.1.8.

4.2.8 Reliability and Maintenance Value Set

The reliability and maintenance category value set is as follows:

$$V_{RM} = .15V_{8.1} + .1V_{8.2} + .1V_{8.3} + .3V_{8.4} + .1V_{8.5} + .25V_{8.6}$$

The value functions and value judgment curves for parameters $V_{8.1}$ through $V_{8.6}$ are found in Section 4.1.9.

4.3 System Value Set

A total AAPS value set which combines the category value sets into one equation was developed. This value set will be used to produce the structured value of the AAPS candidates.

$$V_{System} = (V_E)(V_S)\left[.21V_{OP} + .2V_{ST} + .2V_A + .15V_{PF} + .12V_{OE} + .12V_{RM}\right]$$

The two critical categories, emissions and safety, are considered as factors in the system value set. An AAPS candidate which has high emissions or poor safety characteristics will therefore receive a low system structured value. The categories of operating performance (V_{OP}), system technical parameters (V_{ST}) and acceptability (V_A) have 61% of the weight of all terms. These categories are used to evaluate the AAPS candidate's drivability, consumer acceptability and the technical and cost characteristics of the propulsion system. 27% of the weight is assigned to categories which provide an indication of the AAPS candidates productability and maintainability. The category used to evaluate the ability of the AAPS candidate to operate in the climate of the United States is given the remaining 12% of the weight.

SECTION V

ANALYSIS OF MODEL

5.1 Method of Analysis

The AAPS Structured Value Analysis model was tested and analyzed to determine if it performed in the manner desired, to identify critical and non-critical parameters and to identify changes to the model which would improve results. It was decided to subject the SVA model to a sensitivity analysis whereby the contribution of each parameter to the category value could be studied. In order to perform this sensitivity analysis, a computer program was developed and is described in Appendix II.

The category value sets and the value functions for the parameters, as defined in Section 4.0, were programmed into the computer. A data set of parameter values corresponding to the .5 value to the user point (PV.5) (Figure 11), was then used to calculate a base value (CV_B)for the category. The range (R) of the parameter was calculated by taking the absolute value of the difference between the parameter value where value to the user is zero (PV0) and the parameter value where the value to the user is unity (PV1). New parameter value points corresponding to ±10% ($P_{-.1R}$, $P_{.1R}$), ±20% ($P_{-.2R}$, $P_{.2R}$), and ±30% ($P_{-.3R}$, $P_{.3R}$) of the range (R) were calculated.

New category values $CV_{P_{-.1R}}$ and $CV_{P_{+.1R}}$ were then calculated by using $P_{-.1R}$, $P_{+.1R}$ for one parameter in the category value set while holding the other parameters in the value set at $P_{V.5}$. The percentage change in the category base value was then calculated.

VALUE JUDGMENT CURVE

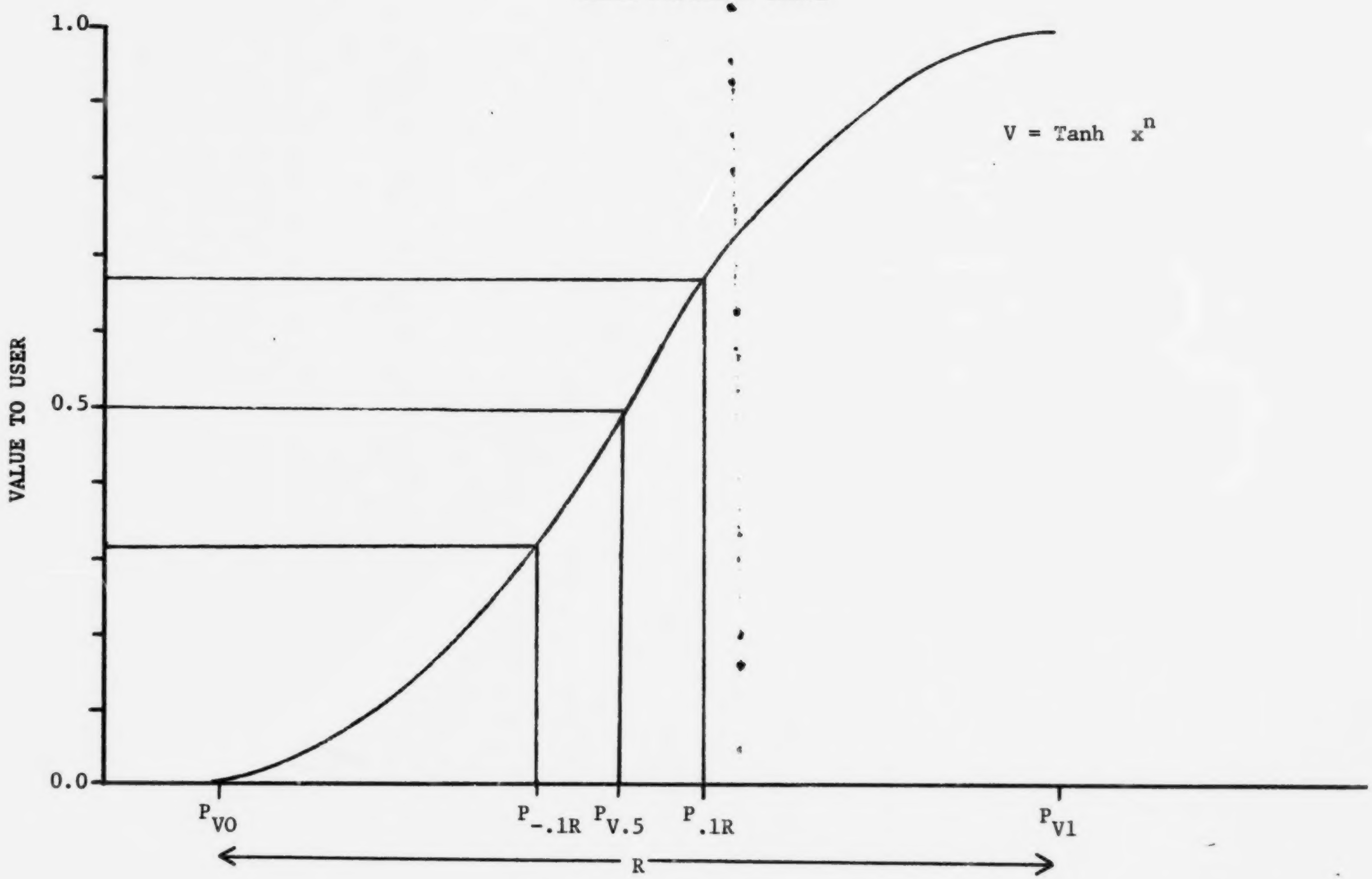


FIGURE 11

PARAMETER VALUES

$$\frac{CV_{P_{-.1R}} - CV_B}{CV_B} \quad \text{and} \quad \frac{CV_{P_{+.1R}} - CV_B}{CV_B}$$

The computer program performs this calculation for each parameter for ±10%, ±20%, and ±30% range. It is then possible to determine the % change in category value resulting from a change in a single parameter value.

Those parameters which, when varied, result in the largest change in the category value are the most sensitive and have the largest influence on the category value.

5.2 Results of Analysis

Each of the eight evaluation categories were subjected to the sensitivity analysis. The results, conclusions and recommendations for each category are discussed below.

5.2.1 Emissions

The results of the sensitivity analysis showed that the CO, NO_x, HC, SO_x and particulates had the greatest effect on the category value. The effect of these parameters on the category value ranged between 24.9% to 35.2% for a change in parameter value equivalent to 10% of the range; 47.0 to 67.4% for a 20% change and 64.8% to 88.7% for a 30% change as is shown in Table III. The order of parameters in terms of effect of the category value remained constant until the 30% variation when internal noise dropped from 7th to 9th place.

It can be concluded that the emission category would produce results as desired. The more important emissions do have the greatest impact on the results of the model. It can also be concluded that deletion of the idle noise and maximum noise parameters from future AAPS SVA models will not have a significant impact on the model results.

It is therefore recommended that the idle noise and maximum noise parameter be deleted from further consideration as an evaluation parameter. It is also recommended that additional weight be given to internal noise so that it remains in its relative position of importance throughout the entire range of variation.

5.2.2 Operating Performance

The sensitivity analysis of the operating performance category was conducted using the design performance values contained in the "Design Goals - Six Passenger Automobile" (Appendix I) rather than the parameter value corresponding to a value to the user of .5. This change was necessary due to the fact that several of the value judgment curves have two parameter values corresponding to a .5 value to the user.

Table IV presents the results of the sensitivity analysis for the operating performance category. As was expected, the category value is not extremely sensitive to any particular parameter. This is because the parameters have weights which are very nearly equal. The major impact on the category value occurs when a break point in a value judgment curve is reached. For example, the category value is sensitive to the cruise speed parameter when the parameter value drops below 80 miles per hour or exceeds 85 miles per hour. This fact is evident in the 20% variation listing in Table IV.

While the results of the sensitivity analysis were as expected, MITRE recommends the parameter list be reviewed closely to determine if some of the parameters could be deleted, and thus the sensitivity of other parameters increased. Those parameters which MITRE recommends deleting are the following:

1. DOT Highspeed Pass - The parameter acceleration - 25-70 provides a similar measure of passing ability, and has been used in performance tests by Union Oil Company(23) and Consumer's Report.
2. Maximum Speed - MITRE considers this parameter to be important from a safety standpoint. Therefore, in evaluating the safety of the propulsion system if the AAPS candidate cannot be governed to an acceptable maximum speed, it should be eliminated from consideration. The parameter cruise speed should be the principle speed evaluation parameter.
3. Creep Torque - This parameter could be deleted in favor of the torque parameters contained in the propulsion system technical parameters.

4. Sustained Idle Operations - This parameter could be deleted without causing a major omission in the evaluation of AAPS candidates.

5.2.3 Acceptability

The analysis of the acceptability category showed it performed as expected throughout the entire range of variation with the model being most sensitive to changes in ease of operation and driver comfort. The one exception is the models relatively high sensitivity to ease of starting as can be seen in Table V.

It is recommended that a lesser weight be placed on ease of starting and a somewhat greater weight be placed on versatility of styling. All parameters in this category contribute significantly to the model, therefore, it is recommended that all parameters be retained.

5.2.4 Operating Environment

The category of operating environment performed as desired throughout the range of variation. The model proved to be most sensitive to minimum and maximum temperatures and the effects of adverse weather (Table VI). The impact of varying the values of the dust and reduced operating performance in 75 mile per hour wind parameters had little effect on the model's result. It is, therefore, recommended that these two parameters be deleted from further consideration.

5.2.5 Safety

The computer results for the sensitivity analysis of this category does not reflect the category's sensitivity to the propulsion system safety parameter. This parameter has a value function which is binary.

PARAMETER CODE NAME	PARAMETER
EMCO	Carbon Monoxide Emission
EMNOX	Oxides of Nitrogen Emission
EMHC	Hydrocarbon Emission
EMSOX	Sulfur Oxides Emissions
EMPART	Particulates
LSPNOISE	Maximum Low Speed Noise
INTNOISE	Internal Noise
SMOKE	Smoke
ODOR	Odor
IDLNOISE	Maximum Idle Noise
MAXNOISE	Maximum External Noise

TABLE III

EMISSION CATEGORY SENSITIVITY ANALYSIS

PERCENT VARIATION IS: 10.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
EMCO	2	1	1	-35.162109	30.561569	-1.024700
EMNOX	2	3	2	-33.497696	29.366959	-0.980126
EMHC	2	2	3	-31.275192	28.099030	-0.925706
EMSOX	2	4	4	-26.459564	26.200150	-0.821020
EMPART	2	5	5	-24.983307	25.845032	-0.792467
LSPNOISE	1	5	6	-7.037911	6.038696	-0.203878
INTNOISE	1	6	7	-7.186053	5.849435	-0.203237
SMOKE	1	1	8	-5.228005	5.178307	-0.162245
ODOR	1	2	9	-4.918939	5.213264	-0.157972
IDLNOISE	1	4	10	-4.929669	4.243008	-0.143012
MAXNOISE	1	3	11	-4.259328	3.649273	-0.123303

PERCENT VARIATION IS: 20.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
EMCO	2	1	1	-67.490234	53.806717	-1.891146
EMNOX	2	3	2	-64.711792	52.095535	-1.821148
EMHC	2	2	3	-60.556778	50.588120	-1.732865
EMSOX	2	4	4	-50.335358	49.664627	-1.559104
EMPART	2	5	5	-47.016190	50.249985	-1.516481
LSPNOISE	1	5	6	-13.587985	10.591991	-0.376991
INTNOISE	1	6	7	-12.342190	9.547833	-0.341288
SMOKE	1	1	8	-9.958401	9.828992	-0.308506
ODOR	1	2	9	-9.190122	10.277217	-0.303516
IDLNOISE	1	4	10	-9.495435	7.448288	-0.264170
MAXNOISE	1	3	11	-8.204502	6.392829	-0.227588

PERCENT VARIATION IS: 30.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
EMCO	2	1	1	-88.702652	70.211533	-2.477638
EMNOX	2	3	2	-86.331955	68.442917	-2.413102
EMHC	2	2	3	-82.157669	67.287277	-2.330003
EMSOX	2	4	4	-69.410294	68.850845	-2.155637
EMPART	2	5	5	-64.765625	71.223129	-2.120208
LSPNOISE	1	5	6	-17.888641	13.794860	-0.493979
SMOKE	1	1	7	-13.760189	13.651256	-0.427373
ODOR	1	2	8	-12.619572	14.743584	-0.426620
INTNOISE	1	6	9	-13.848045	11.656675	-0.397645
IDLNOISE	1	4	10	-12.474370	9.705009	-0.345800
MAXNOISE	1	3	11	-10.749595	8.318022	-0.297284

PARAMETER CODE NAME	PARAMETER
AAC2570	Acceleration - 25 - 70 MPH
CRSSPD	Cruise Speed
HISPPASS	DOT High Speed Pass
RNGCRSE	Range - Cruise
SPDGRADE	Grade Speed
ACCTENSC	Acceleration - 10 Seconds
MAXSPD	Maximum Speed
RNGURBN	Range - Urban
FUELCSP	Idle Operations - Fuel Consumption
SUSIDLE	Idle Operations - Sustained
START	Starting Time - 65% Full Power
COLDSOAK	Starting - Cold Soak
CRPTRQ	Idle Operations - Creep Torque
STRTREL1	Starting - Reliability

TABLE IV

OPERATING PERFORMANCE CATEGORY SENSITIVITY ANALYSIS

```
PERCENT VARIATION IS:   10.00

  NAME       I   J  ORDER    PCT.  POS.       PCT.  NEG.      PCT. DIFF.
AAC2570      1   8    1       -2.906960        2.906972       -3.444427
CRSSPD       1  10    2       -5.063779       0.0             -3.000003
HISPPASS     1   9    3       -2.700673        1.687932       -2.600002
RNGCRSE      1  14    4        2.179513       -1.608060        2.243924
SPDGRADE     1  12    5       -1.629822        1.818521       -2.042949
ACCTENSC     1   7    6        0.0            -3.420275        2.026320
MAXSPD       1  11    7       -1.687922        1.687922       -1.999998
RNGURBN      1  13    8        1.783228       -1.315693        1.835936
FUELCSP      1   4    9       -1.051214        1.305833       -1.396418
SUSIDLE      1   6   10        1.172879       -0.985075        1.278465
START        1   1   11       -0.847100        1.086729       -1.145684
COLDSOAK     1   2   12       -0.875331        1.036082       -1.132404
CRPTRQ       1   5   13       -0.939469        0.804362       -1.033121
STRTREL1     1   3   14       -0.301523        0.0            -0.178635
PERCENT VARIATION IS:   20.00

  NAME       I   J  ORDER    PCT.  POS.       PCT.  NEG.      PCT. DIFF.
AAC2570      1   8    1       -5.813944        3.750942       -5.666655
CRSSPD       1  10    2      -10.127548       -1.125292       -5.333328
RNGCRSE      1  14    3        4.909123       -2.736542        4.529625
HISPPASS     1   9    4       -5.401349        1.687932       -4.199999
ACCTENSC     1   7    5        0.0            -6.840538        4.052632
SPDGRADE     1  12    6       -2.932093        3.614669       -3.878587
RNGURBN      1  13    7        4.016547       -2.238993        3.706056
MAXSPD       1  11    8       -3.375846        2.813205       -3.666663
FUELCSP      1   4    9       -1.776608        2.712022       -2.659261
SUSIDLE      1   6   10        2.415832       -1.747482        2.466529
START        1   1   11       -1.445447        2.345597       -2.245980
COLDSOAK     1   2   12       -1.551035        2.152451       -2.194106
CRPTRQ       1   5   13       -1.914663        1.436493       -1.985371
STRTREL1     1   3   14       -0.914699        0.0            -0.541908

PERCENT VARIATION IS:   30.00

  NAME       I   J  ORDER    PCT.  POS.       PCT.  NEG.      PCT. DIFF.
AAC2570      1   8    1       -8.720925        3.750942       -7.388878
RNGCRSE      1  14    2        7.917861       -3.500901        6.764972
CRSSPD       1  10    3      -15.191318       -4.501138       -6.333327
ACCTENSC     1   7    4       -0.295396      -10.260813        5.903947
HISPPASS     1   9    5       -8.102034        1.687932       -5.800002
RNGURBN      1  13    6        6.478249       -2.864383        5.534983
SPDGRADE     1  12    7       -3.869268        5.163310       -5.351293
MAXSPD       1  11    8       -5.063769        2.813205       -4.666662
FUELCSP      1   4    9       -2.193096        4.049457       -3.698360
SUSIDLE      1   6   10        3.537804       -2.303363        3.460562
START        1   1   11       -1.831068        3.663886       -3.255450
COLDSOAK     1   2   12       -2.030895        3.246504       -3.126561
CRPTRQ       1   5   13       -2.779732        1.902278       -2.773827
STRTREL1     1   3   14       -1.900758        0.0            -1.126092
```

PARAMETER CODE NAME	PARAMETER
EASEOPER	Ease of Operation
DRIVCOMF	Driver Comfort
EASESTRT	Ease of Starting
VERSSTYL	Versatility - Styling
VMINSIZE	Versatility - Minimum Size
VMAXSIZE	Versatility - Maximum Size

TABLE V

ACCEPTABILITY CATEGORY SENSITIVITY ANALYSIS

```
PERCENT VARIATION IS:   10.00

  NAME       I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
EASEOPER     1    1     1       6.567370         -7.469754         6.975143
DRIVCOMF     1    3     2       5.720240         -5.713965         5.681735
EASESTRT     1    2     3       5.191410         -4.656161         4.893327
VERSSTYL     1    4     4       4.273085         -4.819981         4.518407
VMINSIZE     1    5     5      -3.906994          3.543061        -3.701984
VMAXSIZE     1    6     6       3.647887         -3.298865         3.451889


PERCENT VARIATION IS:   20.00

  NAME       I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
EASEOPER     1    1     1      11.916721        -15.234361        13.491559
DRIVCOMF     1    3     2      10.734398        -10.787200        10.694229
EASESTRT     1    2     3       9.937490         -8.278275         9.051538
VERSSTYL     1    4     4       7.778472         -9.779969         8.724910
VMINSIZE     1    5     5      -7.478605          6.372247        -6.882584
VMAXSIZE     1    6     6       7.094137         -5.971404         6.492358


PERCENT VARIATION IS:   30.00

  NAME       I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
EASEOPER     1    1     1      16.001373        -22.379547        19.071732
DRIVCOMF     1    3     2      14.543285        -14.837646        14.599586
VERSSTYL     1    4     3      10.471056        -14.266652        12.292337
EASESTRT     1    2     4      13.295743        -10.819407        11.982983
VMINSIZE     1    5     5     -10.012710          8.449469        -9.173983
VMAXSIZE     1    6     6       9.732804         -7.979618         8.801424
```

PARAMETER CODE NAME	PARAMETER
MINTEMP	Engine Operating Temperature - Minimum
MAXTEMP	Engine Operating Temperature - Maximum
RDPWRWEA	Reduced Power Due to Adverse Weather
RP40WIND	Reduced Power - 40 MPH Wind
RDPWRALT	Reduced Power at 11000 feet
DUST	Operability in Dust or Sand
RP75WIND	Reduced Power - 75 MPH Wind

TABLE VI

OPERATING ENVIRONMENT CATEGORY SENSITIVITY ANALYSIS

```
PERCENT VARIATION IS:    10.00

  NAME       I    J   ORDER   PCT.  POS.      PCT.  NEG.      PCT. DIFF.
MINTEMP      2    2     1      35.000076     -31.314758       4.028062
MAXTEMP      2    1     2      32.495850     -29.151474       3.744549
RDPWRWEA     2    3     3     -30.080704      31.117126      -3.717248
RP40WIND     1    2     4     -11.340745      12.095641      -1.423560
RDPWRALT     1    1     5      -8.269497       9.138345      -1.057378
DUST         1    4     6      -4.843318       4.437011      -0.563701
RP75WIND     1    3     7      -1.638904       1.742699      -0.205404


PERCENT VARIATION IS:    20.00

  NAME       I    J   ORDER   PCT.  POS.      PCT.  NEG.      PCT. DIFF.
MINTEMP      2    2     1      66.178925     -55.504654       7.391238
MAXTEMP      2    1     2      62.919495     -52.358154       7.002132
RDPWRWEA     2    3     3     -55.431641      59.248978      -6.965869
RP40WIND     1    2     4     -20.862137      23.586273      -2.699863
RDPWRALT     1    1     5     -15.111446      18.253387      -2.026629
DUST         1    4     6      -9.184214       8.018209      -1.044900
RP75WIND     1    3     7      -2.415890       3.573874      -0.363827


PERCENT VARIATION IS:    30.00

  NAME       I    J   ORDER   PCT.  POS.      PCT.  NEG.      PCT. DIFF.
MINTEMP      2    2     1      86.447739     -72.547394       9.657598
RDPWRWEA     2    3     2     -74.090393      81.308762      -9.439170
MAXTEMP      2    1     3      85.429367     -69.404892       9.404856
RP40WIND     1    2     4     -28.070938      33.154282      -3.718911
RDPWRALT     1    1     5     -20.346359      26.191589      -2.826784
DUST         1    4     6     -12.128532      10.694563      -1.386308
RP75WIND     1    3     7      -2.415890       5.473836      -0.479234
```

PARAMETER CODE NAME	PARAMETER
SFSERV	Safety - Service
SFPROD	Safety - Production
SFLSACC	Safety-Energy Supply Low Speed Accident
SFNORMOP	Safety-Energy Supply Normal Operation
SFHSACC	Safety-Energy Supply High Speed Accident
SFPROPSY	Propulsion System Safety

TABLE VII

SAFETY CATEGORY SENSITIVITY ANALYSIS

```
PERCENT VARIATION IS:   10.00


  NAME        I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
SFSERV        2    2     1        38.296860      -34.060852         2.229057
SFPROD        2    1     2        38.296860      -34.060852         2.229057
SFLSACC       2    6     3        30.392899      -28.630737         1.818287
SFNORMOP      2    4     4        30.392853      -28.630768         1.818286
SFHSACC       2    5     5        30.392853      -28.630737         1.818285
SFPROPSY      2    3     6       -99.999969      -99.999969         0.0
DUMYTERM      1    1     7         0.0             0.0              0.0


PERCENT VARIATION IS:   20.00


  NAME        I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
SFSERV        2    2     1        71.082672      -59.533081         4.023760
SFPROD        2    1     2        71.082672      -59.533081         4.023760
SFLSACC       2    6     3        58.037933      -52.541245         3.406510
SFHSACC       2    5     4        58.037933      -52.541245         3.406510
SFNORMOP      2    4     5        58.037811      -52.541214         3.406507
SFPROPSY      2    3     6       -99.999969      -99.999969         0.0
DUMYTERM      1    1     7         0.0             0.0              0.0


PERCENT VARIATION IS:   30.00


  NAME        I    J   ORDER    PCT.  POS.        PCT.  NEG.       PCT. DIFF.
SFSERV        2    2     1        90.288345      -76.655029         5.142871
SFPROD        2    1     2        90.288345      -76.655029         5.142871
SFLSACC       2    6     3        78.905075      -70.719666         4.609351
SFHSACC       2    5     4        78.905014      -70.719666         4.609349
SFNORMOP      2    4     5        78.905014      -70.719666         4.609349
SFPROPSY      2    3     6       -99.999969      -99.999969         0.0
DUMYTERM      1    1     7         0.0             0.0              0.0
```

That is, if the system is safe, the value to the user is 1; if it is not safe the value to the user is 0 and consequently the entire category value is 0. Therefore, the category value is most sensitive to any change in value of this parameter.

Table VII shows the safety in service and safety in production to be the most critical parameters. It is MITRE's conclusion that the model should be more sensitive to the safety of the energy storage parameters than safety in service and safety in production. It is therefore recommended that the slopes for safety in production (Curve 5.5) and safety in service (Curve 5.6) curves originally agreed to by DAAPSD and MITRE is reduced to a value below the slope of the other curves. It is also recommended that all six safety parameters be retained in the model.

5.2.6 Personnel and Facilities

In this category the sensitivity analysis shows a very logical ranking of the parameters. The most critical parameter is time to consumer availability which shows a variation in the base value of 0.194 over the span of ±10% from the 0.5 value (Table VIII). This, of course, is due to the intentionally high weighting, 0.20, given to this parameter. All the other parameters have weightings of 0.10 or less and are thus closely grouped in variation from 0.033 to 0.128 over the 10% span. The parameter complexity of production changeover is ranked last, more on the basis of the function itself rather than the weighting assigned. This is acceptable since this parameter was not intended to be a key one in this category.

5.2.7 Propulsion System Technical Performance

The sensitivity and ranking of the propulsion system technical performance parameters, based on a ±10% variation about the mid-value point, is presented in Table IX. The relative ranking of the parameter is generally what one would intuitively expect.

The category value set is most sensitive to overall propulsion system weight and volume, with weight having the more important role. Fuel cost is next in the ranking. Although costs in general are considered elsewhere, specific fuel cost is considered to be an important measure of a propulsion system's value from the standpoint of the consumption of natural resources. The power conditioner efficiency at maximum continuous horsepower is next in importance, ranking ahead of energy converter and overall system efficiencies because it plays an important role in determining not only operating cost, but also the weight, volume, and the initial cost of the energy converter and the energy storage system.

The overall propulsion system efficiencies (19th and 23rd in the ranking) appear to be lower in importance than one would expect. However, since there are two overall efficiency parameters (one for each mode), the effective sensitivity for overall system efficiency will be the sum of the two individual sensitivites. Therefore, the effective ranking for overall system efficiency becomes 9th in order of importance.

Finally, the sensitivity of individual component specific weight and volume are clustered together at the bottom six positions in the

PARAMETER CODE NAME	PARAMETER
TIMEAVL	Time to Consumer Availability
SERVFAC	Lead Time - Field Service Changeover
EDLVLSRP	Education Level - Service
CPLXSERV	Complexity of Field Service Changeover
SERVPERS	Lead Time for Service Training
PRODFAC	Lead Time - Production Changeover
PRODPERS	Lead Time for Production Training
EDLVLPRD	Education Level - Production
AVLENGST	Availability of Energy Stations
CPLXPROD	Complexity of Production Changeover

TABLE VIII

PERSONNEL AND FACILITIES CATEGORY SENSITIVITY ANALYSIS

```
PERCENT VARIATION IS:   10.00

  NAME      I   J  ORDER   PCT.  POS.      PCT.  NEG.     PCT. DIFF.
TIMEAVL     1   1    1     -17.208344      15.128437     -15.472227
SERVFAC     1   4    2      -3.676622       3.279859      -3.328478
EDLVLSRP    1  10    3      -3.513943       3.029752      -3.130972
CPLXSERV    1   5    4       2.945989      -2.847939       2.772229
SERVPERS    1   9    5      -2.717609       2.934466      -2.704358
PRODFAC     1   2    6      -2.860669       2.691848      -2.656722
PRODPERS    1   7    7      -2.733206       2.731624      -2.614766
EDLVLPRD    1   8    8      -2.715742       2.349497      -2.423573
AVLENGST    1   6    9       1.669640      -1.712156       1.618093
CPLXPROD    1   3   10       1.337590      -1.337590       1.279998


PERCENT VARIATION IS:   20.00

  NAME      I   J  ORDER   PCT.  POS.      PCT.  NEG.     PCT. DIFF.
TIMEAVL     1   1    1     -20.914841      19.569962     -19.370819
SERVFAC     1   4    2      -6.907936       5.812591      -6.086409
EDLVLSRP    1  10    3      -6.712207       5.273013      -5.734587
CPLXSERV    1   5    4       5.616586      -5.313612       5.229789
SERVPERS    1   9    5      -5.013230       5.805465      -5.176436
PRODFAC     1   2    6      -5.546988       4.986445      -5.039948
PRODPERS    1   7    7      -5.179049       5.202183      -4.967123
EDLVLPRD    1   8    8      -4.898374       4.003203      -4.259151
AVLENGST    1   6    9       3.059975      -3.220685       3.005116
CPLXPROD    1   3   10       2.675181      -2.675193       2.560001


PERCENT VARIATION IS:   30.00

  NAME      I   J  ORDER   PCT.  POS.      PCT.  NEG.     PCT. DIFF.
TIMEAVL     1   1    1     -21.000549      19.569962     -19.411835
SERVFAC     1   4    2      -8.882531       7.618824      -7.895428
EDLVLSRP    1  10    3      -8.771500       6.784958      -7.443320
SERVPERS    1   9    4      -6.795135       8.312596      -7.228619
CPLXSERV    1   5    5       7.698914      -7.259194       7.157027
PRODFAC     1   2    6      -7.723005       6.793503      -6.945735
PRODPERS    1   7    7      -7.119823       7.244108      -6.872731
EDLVLPRD    1   8    8      -5.917930       5.046141      -5.245996
AVLENGST    1   6    9       4.048337      -4.355285       4.020893
CPLXPROD    1   3   10       4.012771      -2.925983       3.319996
```

TABLE IX

PROPULSION SYSTEM TECHNICAL PARAMETER SENSITIVITY ANALYSIS

RANKING	PARAMETER NUMBER	NAME	PERCENT CHANGE
1	31	O.P.S.-Total Weight	-.0870
2	30	O.P.S.-Total Volume	-.0545
3	3	E.S.-Specific Cost (Consumable)	-.0504
4	26	P.C.-Efficiency at max. Cont. HP	+.0460
5	18	E.C.-Overload Capability	+.0358
6	5	E.S.-Known Fuel Reserves	+.0331
7	6	E.S.-Ease of Refueling	+.0325
8	19	E.C.-Sensitivity to Fuel Quality	-.0325
9	12	E.C.-Stall/Design pt. Torque	+.0315
10	27	P.C.-Effectiveness in Reverse Power Direction	+.0310
11	32	O.P.S.-Use of Scarce Materials	+.0290
12	14	E.C.-Regenerative Power Efficiency	+.0260
13	25	P.C.-Reverse Power Effectiveness	+.0258
14	22	P.C.-Specific Cost	-.0212
15	16	E.C.-Efficiency at Max. Cont. HP	+.0204
16	10	E.C.-Power Range-Minimum HP	-.0198
17	23	P.C.-Power Range-Minimum HP	-.0189
18	13	E.C.-Minimum/Design Point/RPM	-.0178
19	28	O.P.S.-Provision Efficiency of Wheel, Mode 1	+.0177
20	11	E.C.-Power Range-Maximum HP	+.0171
21	24	P.C.-Power Range-Maximum HP	+.0170
22	15	E.C.-Absorption Power Effectiveness	+.0165
23	29	O.P.S.-Propulsion Efficiency at Wheel, Mode 2	+.0144
24	9	E.C.-Specific Cost	-.0114
25	17	E.C.-Response to Load Change	-.00975
26	4	E.S.-Specific Cost (non-consumable)	-.0082
27	21	P.C.-Specific Weight	-.00508

TABLE IX (CONT'D)

RANKING	PARAMETER NUMBER	NAME	PERCENT CHANGE
28	8	E.C.-Specific Weight	-.00275
29	7	E.C.-Specific Volume	-.00184
30	1	E.S.-Specific Volume	-.000994
31	2	E.S.-Specific Weight	-.000144
32	20	P.C.- Specific Volume	-.0000048

E.S. = Energy Storage
E.C. = Energy Converter
P.C. = Power Conditioner
O.P.S. = Overall Propulsion System

ranking, and might legitimately be dropped from consideration. However, this is not recommended since these parameters offer an insight into overall system weight and volume which are, as stated earlier, the most important of all parameters in this category.

5.2.8 Reliability and Maintenance

The sensitivity and ranking of the reliability and maintenance parameters are presented in Table X. The relative ranking conforms to the weighting factors applied to each term in the value set. The category value set is relatively insensitive to changes in the last three parameters: expense of unscheduled repairs, ease of routine service and period between routine services. However, it is recommended that these three parameters be retained in the value set as they provide a measure of reliability and maintenance which is important to the ultimate consumer.

TABLE X

RELIABILITY AND MAINTENANCE CATEGORY SENSITIVITY ANALYSIS

PERCENT VARIATION IS: 10.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
DESIGN LIFE	1	4	1	11.919704	-10.839664	11.718886
MILES BETWEEN FAILURES	1	6	2	8.317348	-7.874977	8.337491
SYSTEM COMPLEXITY	1	1	3	-4.696195	5.673153	-5.339217
EXPENSE OF UNSCHEDULE REPAIR	1	3	4	-3.499930	3.664239	-3.688860
EASE OF ROUTINE SERVICE	1	2	5	3.029963	-3.205325	3.210574
PERIOD BETWEEN ROUTINE SERVICES	1	5	6	2.549343	-3.036468	2.876156

PERCENT VARIATION IS: 20.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
DESIGN LIFE	1	4	1	21.536423	-18.848450	20.794327
MILES BETWEEN FAILURES	1	6	2	15.509501	-14.245680	15.321057
SYSTEM COMPLEXITY	1	1	3	-8.203454	11.664642	-10.230160
EXPENSE OF UNSCHEDULE REPAIR	1	3	4	-6.380380	6.811767	-6.792688
EASE OF ROUTINE SERVICE	1	2	5	5.473700	-6.115570	5.967360
PERIOD BETWEEN ROUTINE SERVICES	1	5	6	4.557423	-6.380115	5.631781

PERCENT VARIATION IS: 30.00

NAME	I	J	ORDER	PCT. POS.	PCT. NEG.	PCT. DIFF.
DESIGN LIFE	1	4	1	26.705795	-24.002747	26.110031
MILES BETWEEN FAILURE	1	6	2	20.421082	-18.787521	20.188660
SYSTEM COMPLEXITY	1	1	3	-10.623020	14.525805	-12.949228
EXPENSE OF UNSCHEDULED REPAIR	1	3	4	-8.469700	7.781907	-8.368015
PERIOD BETWEEN ROUTINE SERVICE	1	5	5	6.060457	-9.662512	8.095819
EASE OF ROUTINE SERVICE	1	2	6	7.158338	-8.380149	8.000827

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APPENDIX I

AIR POLLUTION CONTROL OFFICE

ADVANCED AUTOMOTIVE POWER SYSTEMS PROGRAM

"Vehicle Design Goals - Six Passenger Automobile"

(Revision B - February 11, 1971 - 11 Pages)

The design goals presented below are intended to provide:

A common objective for prospective contractors.

Criteria for evaluating proposals and selecting a contractor.

Criteria for evaluating competitive power systems for entering first generation system hardware.

The derived criteria are based on typical characteristics of the class of passenger automobiles with the largest market volume produced in the U.S. during the model years 1969 and 1970. It is noted that emissions, volume and most weight characteristics presented are maximum values while the performance characteristics are intended as minimum values. Contractors and prospective contractors who take exceptions must justify these exceptions and relate these exceptions to the technical goals presented herein.

1. Vehicle weight without propulsion system - W_o.

   W_o is the weight of the vehicle without the propulsion system and includes, but is not limited to: body, frame, glass and trim, suspension, service brakes, seats, upholstery, sound absorbing materials, insulation, wheels (rims and tires), accessory ducting, dashboard instruments and accessory wiring, passenger compartment heating and cooling devices and all other components not included in the propulsion system. It also includes the air conditioner compressor, the power steering pump, and the power brakes actuating device.

   W_o is fixed at 2700 lbs.

2. Propulsion system weight - W_p

   W_p includes the energy storage unit (including fuel and containment), power converter (including both functional components and controls) and power transmitting components to the driven wheels. It also includes the exhaust system, pumps, motors, fans and fluids necessary for operation of the propulsion system, and any propulsion system heating or cooling devices.

The maximum allowable propulsion system weight, W_{pm}, is 1600 lbs. However, light weight propulsion systems are highly desired. (Equivalent 1970 propulsion system weight with a spark ignition engine is 1300 lbs.)

3. Vehicle curb weight - W_c

$W_c = W_o + W_p$

The maximum allowable vehicle curb weight, W_{cm}, is 4300 lbs. (2700 + 1600 max. = 4300)

4. Vehicle test weight - W_t

$W_t = W_c + 300$ lbs. W_t is the vehicle weight at which all accelerative maneuvers, fuel economy and emissions are to be calculated. (Items 8c, 8d, 8e)

The maximum allowable test weight, W_{tm}, is 4600 lbs. (2700 + 1600 max. + 300 = 4600)

5. Gross vehicle weight - W_g

$W_g = W_c + 1000$ lbs. W_g is the gross vehicle weight at which sustained cruise grade velocity capability is to be calculated. (Item 8f) The 1000 lbs load simulates a full load of passengers and baggage.

The maximum allowable gross vehicle weight, W_{gm}, is 5300 lbs. (2700 + 1600 max. + 1000 = 5300)

6. Propulsion system volume - V_p

V_p includes all items identified under item 2. V_p shall be packagable in such a way that the volume encroachment on either the passenger or luggage compartment is not significantly different than today's (1970) standard full size family car. Necessary external appearance (styling) changes will be minor in nature. V_p shall also be packagable in such a way that the handling characteristics of the vehicle do not depart significantly from a 1970 full size family car.

The maximum allowable volume assignable to the propulsion system, V_{pm}, is 35 ft^3.

7. Emission Goals

The vehicle when tested for emissions in accordance with the procedure outlined in the November 10, 1970 Federal Register shall have a weight of W_t. The emission goals for the vehicle are:

Hydrocarbons* - 0.14 grams/mile maximum
Carbon monoxide - 4.7 grams/mile maximum
Oxides of nitrogen** - 0.4 grams/mile maximum
Particulates - 0.03 grams/mile maximum

*Total hydrocarbons (using 1972 measurement procedures) plus total oxygenates. Total oxygenates including aledhydes will not be more than 10 percent by weight of the hydrocarbons or 0.014 grams/mile, whichever is greater.

**measured or computed as NO_2.

8. Start up, Acceleration, and Grade Velocity Performance.

a. Start up:

The vehicle must be capable of being tested in accordance with the procedure outlined in the November 10, 1970 Federal Register without special startup/warmup procedures.

The maximum time from key on to reach 65 percent full power is 45 sec. Ambient conditions are 14.7 psia pressure, 60° F temperature.

Powerplant starting techniques in low ambient temperatures shall be equivalent to or better than the typical automobile spark-ignition engine. Conventional spark-ignition engines are deemed satisfactory if after a 24 hour soak at -20° F the engine achieves a self-sustaining idle condition without further driver input within 25 seconds. No starting aids external to the normal vehicle system shall be needed for -20° F starts or higher temperatures.

b. Idle operation conditions:

The fuel consumption rate at idle operating condition will not exceed 14 percent of the fuel consumption rate at the maximum design power condition. Recharging of energy storage systems is exempted from this requirement. Air conditioning is off, the power steering pump and power brake actuating device, if directly engine driven, are being driven but are unloaded.

The torque at transmission output during idle operation (idle creep torque) shall not exceed 40 foot-pounds, assuming conventional rear axle ratios and tire sizes. This idle creep torque should result in level road operation in high gear which does not exceed 18 mph.

c. Acceleration from a standing start:

The minimum distance to be covered in 10.0 sec. is 440 ft. The maximum time to reach a velocity of 60 mph is 13.5 sec. Ambient conditions are 14.7 psia, 85° F. Vehicle weight is W_t. Acceleration is on a level grade and initiated with the engine at the normal idle condition.

d. Acceleration in merging traffic:

The maximum time to accelerate from a constant velocity of 25 mph to a velocity of 70 mph is 15.0 sec. Time starts when the throttle is depressed. Ambient conditions are 14.7 psia, 85° F. Vehicle weight is W_t, and acceleration is on level grade.

e. Acceleration, DOT High Speed Pass Maneuver:

The maximum time and maximum distance to go from an initial velocity of 50 mph with the front of the automobile (18 foot length assumed) 100 feet behind the back of a 55 foot truck traveling at a constant 50 mph to a position where the back of the automobile is 100 feet in front of the front of the 55 foot truck is, 15 sec. and 1400 ft. The entire maneuver takes place in a traffic lane adjacent to the lane in which the truck is operated. Vehicle will be accelerated until the maneuver is completed or until a maximum speed of 80 mph is attained, whichever occurs first. Vehicle acceleration ceases when a speed of 80 mph is attained, the maneuver then being completed at a constant 80 mph. (This does not imply a design requirement limiting the maximum vehicle speed to 80 mph.) Time starts when the throttle is depressed. Ambient conditions are 14.7 psia, 85° F. Vehicle weight is W_t, and acceleration is on level grade.

f. Grade velocity:

The vehicle must be capable of starting from rest on a 30 percent grade and accelerating to 15 mph and sustaining it. This is the steepest grade on which the vehicle is required to operate in either the forward or reverse direction.

The minimum cruise velocity that can be continuously maintained on a 5 percent grade with an accessory load of 4 hp shall be not less than 60 mph.

The vehicle must be capable of achieving a velocity of 65 mph up a 5 percent grade and maintaining this velocity for a period of 180 seconds when preceded and followed by continuous operation at 60 mph on the same grade (as above).

The vehicle must be capable of achieving a velocity of 70 mph up a 5 percent grade and maintaining this velocity for a period of 100 seconds when preceded and followed by continuous operation at 60 mph on the same grade (as above).

The minimum cruise velocity that can be continuously maintained on a level road (zero grade) with an accessory load of 4 hp shall be not less than 85 mph with a vehicle weight of W_t.

Ambient conditions for all grade specifications are 14.7 psia 85° F. Vehicle weight is W_g for all grade specifications except the zero grade specification.

The vehicle must be capable of providing performance (Paragraphs 8c, 8d, 8e 8f)within5 percent of the stated 85° F values, when operated at ambient temperatures from -20° F to 105° F.

9. Minimum vehicle range:

Minimum vehicle range without supplementing the energy storage will be 200 miles. The minimum range shall be calculated for, and applied to each of the two following modes: 1) A city-suburban mode, and 2) a cruise mode.

Mode 1: Is the driving cycle which appears in the November 10, 1970 Federal Register. For vehicles whose performance does not depend on the state of energy storage, the range may be calculated for one cycle and ratioed to 200 miles. For vehicles whose performance does depend on the state of energy storage the Federal driving cycle must be repeated until 200 miles have been completed.

Mode 2: Is a constant 70 mph cruise on a level road for 200 miles.

The vehicle weight for both modes shall be, initially, W_t. The ambient conditions shall be a pressure of 14.7 psia, and temperatures of 60° F, 85° F and 105° F. The vehicle minimum range shall not decrease by more than 5 percent at an ambient temperature of -20° F.

For hybrid vehicles, the energy level in the power augmenting device at the completion of operation will be equivalent to the energy level at the beginning of operation.

10. System thermal efficiency:

System thermal efficiency will be calculated by two methods:

A. A "fuel economy" figure based on 1) miles per gallon (fuel type being specified) and 2) the number of Btu per mile required to drive the vehicle over the 1972 Federal driving cycle which appears in the November 10, 1970 Federal Register. Fuel economy is based on the fuel or other forms of energy delivered at the vehicle. Vehicle weight is W_t.

B. A "fuel economy" figure based on 1) miles per gallon (fuel type being specified) and 2) the number of Btu per mile required to drive the vehicle at constant speed, in still air, on level road, at speeds of 20, 30, 40, 50, 60, 70, and 80 mph. Fuel economy is based on the fuel or other forms of energy delivered at the vehicle. Vehicle weight is W_t.

In both cases, the system thermal efficiency shall be calculated with sufficient electrical, power steering and power brake loads in service to permit safe operation of the automobile. Calculations shall be made with and without air conditioning operating. The ambient conditions are 14.7 psia and temperatures of 60° F, 85° F and 105° F. Calculations shall be made with heater operating at ambient conditions of 14.7 psia and 30° F (18,000 Btu/hr).

11. Air Drag Calculation:

The product of the drag coefficient, C_d, and the frontal area, A_f, is to be used in air drag calculations. The product C_dA_f has a value of 12 ft^2. The air density used in computations shall correspond to the applicable ambient air temperature.

12. Rolling Resistance:

Rolling resistance, R, is expressed in the equation $R = W/65\ [1 + (1.4 \times 10^{-3}V) + (1.2\ 10^{-5}V^2)]$ lbs. V is the vehicle velocity in ft/sec. W is the vehicle weight in lbs.

13. Accessory power requirements:

The accessories are defined as subsystems for driver assistance and passenger convenience, not essential to sustaining the engine operation ard include: the air conditioning compressor, the power steering pump, the alternator (except where required to sustain operation), and the power brakes actuating device. The accessories also include a device for heating the passenger compartment if the heating demand is not supplied by waste heat.

Auxiliaries are defined as those subsystems necessary for the sustained operation of the engine, and include condensor fan(s), combustor fan(s), fuel pumps, lube pumps, cooling fluid pumps, working fluid pumps and the alternator when necessary for driving electric motor driven fans or pumps.

The maximum intermittent accessory load, P_{aim}, is 10 hp (plus the heating load, if applicable). The maximum continuous accessory load, P_{acm}, is 7.5 hp (plus the heating load if applicable). The average accessory load, P_{aa}, is 4 hp.

If accessories are driven at variable speeds, the above values apply. If the accessories are driven at constant speed, P_{aim} and P_{acm} will be reduced by 3 hp.

14. Passenger comfort requirements:

Heating and air conditioning of the passenger compartment shall be at a rate equivalent to that provided in the present (1970) standard full size family car.

Present practice for maximum passenger compartment heating rate is approximately 30,000 Btu/hr. For an air conditioning system at 110° F ambient, 80° F and 40% relative humidity air to the evaporator, the rate is approximately 13,000 Btu/hr.

15. Propulsion system operating temperature range:

The propulsion system shall be operable within an expected ambient temperature range of -40° to 125° F.

16. Operational life:

The mean operational life of the propulsion system should be approximately equal to that of the present spark-ignition engine. The mean operational life should be based on a mean vehicle life of 105,000 miles or ten years, whichever comes first.

The design lifetime of the propulsion system in normal operation will be 3500 hours. Normal maintenance may include replacement of accessable minor parts of the propulsion system via a usual maintenance procedure, but the major parts of the system shall be designed for a 3500 hour minimum operation life.

The operational life of an engine shall be determined by structural or functional failure causing repair and replacement costs exceeding the cost of a new or rebuilt engine. (Functional failure is defined as power degradation exceeding 25 percent or top vehicle speed degradation exceeding 9 percent).

17. Noise standards: (Air conditioner not operating)

a. Maximum noise test:

The maximum noise generated by the vehicle shall not exceed 77 dbA when measured in accordance with SAE J986a. Note that the noise level is 77 dbA whereas in the SAE J986a the level is 86 dbA.

b. Low speed noise test:

The maximum noise generated by the vehicle shall not exceed 63 dbA when measured in accordance with SAE J986a except that a constant vehicle velocity of 30 mph is used on the pass-by, the vehicle being in high gear or the highest gear in which it can be operated at that speed.

c. Idle noise test:

The maximum noise generated by the vehicle shall not exceed 62 dbA when measured in accordance with SAE J986a except that the engine is idling (clutch disengaged or in neutral gear) and the vehicle passes by at a speed of less than 10 mph. the microphone will be placed at 10 feet from the centerline of the vehicle pass line.

18. Safety standards:

The vehicle shall comply with all current Department of Transportation Federal Motor Vehicle Safety Standards. Reference DOT/HS 820 083.

19. Reliability and maintainability:

The reliability and maintainability of the vehicle shall equal or exceed that of the spark-ignition automobile. The mean-time-between failure should be maximized to reduce the number of unscheduled service trips. All failure modes should not represent a serious safety hazard during vehicle operation and servicing. Failure propagation should be minimized. The power plant should be designed for ease of maintenance and repairs to minimize costs, maintenance personnel education, and downtime. Parts requiring frequent servicing shall be easily accessable.

20. Cost of ownership:

The net cost of ownership of the vehicle shall be minimized for ten years and 105,000 miles of operation. The net cost of ownership includes initial purchase price (less scrap value), other fixed costs, operating and maintenance costs. A target goal should be to not exceed 110 percent of the average net cost of ownership of the present standard size automobile with spark-ignition engine as determied by the U.S. Department of Commerce 1969-70 statistics on such ownership.

APPENDIX II

STRUCTURED VALUE ANALYSIS

1.0 BASIC CONCEPT

Structured Value Analysis is a method of rank-ordering systems in terms of an abstract set of value criteria. The technique was used previously on several programs, references 1 and 2. The basic comparison is straightforward and merely matches system performance against some value to the user of the system in order to obtain a numerical value versus performance. In later stages this value versus performance can be compared with cost information to obtain such ratios as cost/performance, cost/effectiveness or cost/benefit.

The analysis makes use of value judgments of experts, either individually or by consensus, to provide information and data where hard data is unavailable. As such, much of the information going into the model is subjective, but the results can be of high utility. Structured Value Analysis is an operational technique designed to give answers on gross models without necessitating large amounts of data gathering.

It provides a means for comparing alternate solutions of approaches to model systems with each other. Thus, the results are relative and not absolute.

The objective is to make maximum use of as much information as is available about the system. Much of this information is contained in the experience of experts associated with the system. In some cases this information, often consisting of unstructured or perhaps biased ideas is the only information available. Structured Value Analysis seeks to extract this information, check it for validity, and/or utility in a manner which allows quantification and manipulation. In the absence of objective criteria, the maximum information imbedded in subjective criteria must be utilized effectively. Critical areas are identified by Structured Value Analysis and indicate where further gathering of objective information would be most effective. The method is of high utility for decision making. It is a tool for decision making, not a decision maker in itself.

Reference 3 discusses this in detail and provides a listing of Structured Value Analysis Definitions which are shown here in Table XI. Essentially a set of values, or multiple sets of values for a system model are developed through the use of measurement scales, value functions, and weights. Particular sets of data for candidate systems are evaluated against these sets of values in order to compare candidate sets with all others on a particular scale of values termed structured value.

The value sets thus determined can be examined by techniques of sensitivity analysis to maximize the information known about the value sets and their implications. Critical areas can be identified and through iterative techniques, the value sets can be continuously up-graded.

The Basic Equations and Steps of Structured Value Analysis

There are many ways in which the equations for Structured Value Analysis may be expressed. Two different basic modes are given in reference 3 as follows:

TABLE XI

STRUCTURED VALUE ANALYSIS DEFINITIONS

Model Parameters - The basic kinds of information that make up the model.

Parameter Measurement Scales - The basic scales by which parameters are measured. These consist of a minimum of the range, a maximum of the range, and a scale for expressing increments of the range.

Value - An intrinsic value to the model user expressed as a linear scale between zero and one where zero is minimum value and unity is maximum value to the user.

Value Function - A function relating points on the parameter measurement scale to the value scale for a particular parameter. These functions may result from explicit information or through value judgment.

Term - A parameter related to other parameters by an additive relationship.

Factor - A parameter related to other parameters by a multiplicative relationship.

Weight - The relative importance of terms in a model expressed as a decimal fraction - weights for a set of terms add to unity.

Value Set - A specific set of model parameters made up of terms and factors, expressed in particular measurement scales, value functions and weights.

TABLE XI (CONT'D)

Candidate Set - A particular system to be evaluated against particular value sets.

Data Set - The set of values obtained for a particular candidate set. The data sets are sets of single values for each parameter of the value set.

Structured Value - The resultant value of a particular value set evaluated for a particular data set. This value is between zero and unity and allows many data sets to be ranked numerically in relation to one another.

Sensitivity Analysis - A technique made practical by computer technology that determines the degree that a variation in each parameter affects the output index (structured value here). Those parameters affecting the output the greatest are the most critical parameters.

Group - A set of parameters related by summation or multiplication. In the present program only two groups are allowed. The first group is always additive. The second group can be additive or multiplicative and the two groups are always multiplied together to compute the final value.

Mode 1 - 1 Set of Addends, 1 Set of Factors

$$V_1 = \prod_{j=1}^{n} F_j(x_j) \sum_{i=1}^{m} A_i F_i(x_i) \quad \text{where} \quad \sum_{i=1}^{m} A_i = 1$$

Mode 2 - 2 Sets of Addends

$$V_2 = \sum_{j=1}^{n} A_j F_j(x_j) \sum_{i=1}^{m} A_i F_i(x_i) \qquad \text{where} \quad \sum_{i=1}^{m} A_i = 1 \quad \text{and} \quad \sum_{j=1}^{n} A_j = 1$$

V = Value

A = Weight

F = Value Function

x = Input Value

i&j are indices

In Mode 1, Structured Value is a set of n factors multiplied by a set of m terms. In Mode 2, Structured Value is a set of n terms multiplied by another set of m terms. In this case one of the sets of terms may be considered as a single factor and Mode 1 is then used. In both modes the factors are developed from value functions, F and have a particular value as input X. The terms are derived in the same manner except each is weighted in relative importance by various weights, A, where the total sum of weights equals unity.

The Steps in Setting up a Structured Value Analysis

The steps to be followed in setting up a Structured Value Analysis are as follows:

1. The Model Parameters are Identified

These are the basic system attributes or variables. They represent the kind of information needed to describe and adequately evaluate the systems under study. Any parameter which is so critical that an unacceptable performance of it would justify complete rejection of the candidate system is designated as a factor. All other parameters are terms.

2. Establish Measurement Scales

A minimum and maximum of range and the internal scale between the range limits must be established for each model parameter.

3. Establish Value Functions

Value functions, relating points on the measurement scale to an arbitrary value scale may be determined. With each level of performance there is associated some value on a scale from 0 to 1, where 1 represents the level of performance beyond which no further value accrues. Similarly, the 0 represents the level of performance at which the data no longer has any possible value. The development of these curves is based on information which falls into three categories,

- No information - use best guess and/or linear relationship.
- Biased Information - (i.e., subjective) alter the limits and shape of the curves by using expert opinions.

- o Analytical Information - (exact relationship is known) use an analytic fashion.

4. Establish Weights

In order to determine the relative importance of the terms a weighting is established for each. The relative importance of these terms is usually a judgment expressing value to the user.

5. Test the Value Set

The value sets are subjected to sensitivity analysis to determine the behavior of the value sets and to identify those terms and factors which are most critical. If a value set does not behave in the manner expected, it is then adjusted and the sensitivity analysis repeated until a value set with suitable behavior is obtained.

6. Enter Data Sets

Data sets for candidate systems are then evaluated against value sets to determine their relative value and ranked in terms of the results.

7. Test the Data Sets

A sensitivity analysis may be performed for each data set evaluated to determine which parameters are most critical for that data set.

Assumptions and Critical Factors

A number of important assumptions and critical factors are involved in the use of the model. The principal ones are:

1. Each of the value functions are independent. Thus, changes in performance for one attribute should not cause changes anywhere else in the model. This is not strictly true in all cases. However, in the present study it is assumed that such occurrences are not serious enough to cause any significant changes in the relative system values.

2. A critical assumption is that the parameters chosen to characterize the performance of the various systems, the consensus of experts as to the relative value of these parameters and their characteristics as shown in the value curves, adequately represent the value of the systems to the users. Results cannot be better than the input information. This model is merely a tool for eliciting maximum information from available inputs.

3. It is possible that the performance data for one particular term may reach such a poor level that the zero value corresponding to it does not penalize the overall system sufficiently and that in fact this poor level of performance should cause the entire system to fail. For example, the curve for starting reliability reaches zero value at approximately the 10% failure level. But a zero value for this parameter alone would have little effect on the overall system value since it is only a term. However, consider the case of a system which has a starting failure level of 50%. It is logical to state that such a system should never be accepted even through it may score high in the overall evaluation. The point to be emphasized here is that structured value analysis works best when extreme low values are not encountered for terms. It is assumed that in the

actual use of this model a procedure to identify such extreme cases is incorporated. Thus only those systems whose performance is above some specified extreme levels will be subjected to evaluation by the model.

2.0 OPERATION AND LOGIC OF THE SOFTWARE

The software consists of a main program and four subroutines. The main program controls and links all the subroutines together. Four subroutines, namely BUILDV, BUILDD, EVAUL and SENSI, perform four options (1) build a value set (Valset; (2) build a data set (Datset); (3) evaluate Datset against Valset and (4) perform sensitivity anlaysis of the parameters in a Valset. Any combination of options can be executed during a computer run.

The logic of the main program is shown in Figure 12. A brief description of the computational procedure is as follows:

a. The main program reads in control variables such as the number of groups, number of parameters in each group, data set reference number, number of steps and the option code of each step. According to the option code of each step, the program calls different subroutines to build a Valset, build a Datset, evaluate the Datset against Valset, and perform sensitivity analysis on the parameters in the Valset.

b. If the option code is equal to 1, the main program calls the subroutine BUILDV. According to the number of groups and the parameters in each group, the subroutine reads in the attributes of the parameter and coordinates of the break points (if any) and, computes the slope between the break points. Then, the weights of the parameters for each group are read in. The Valset is printed and can be written on file if requested.

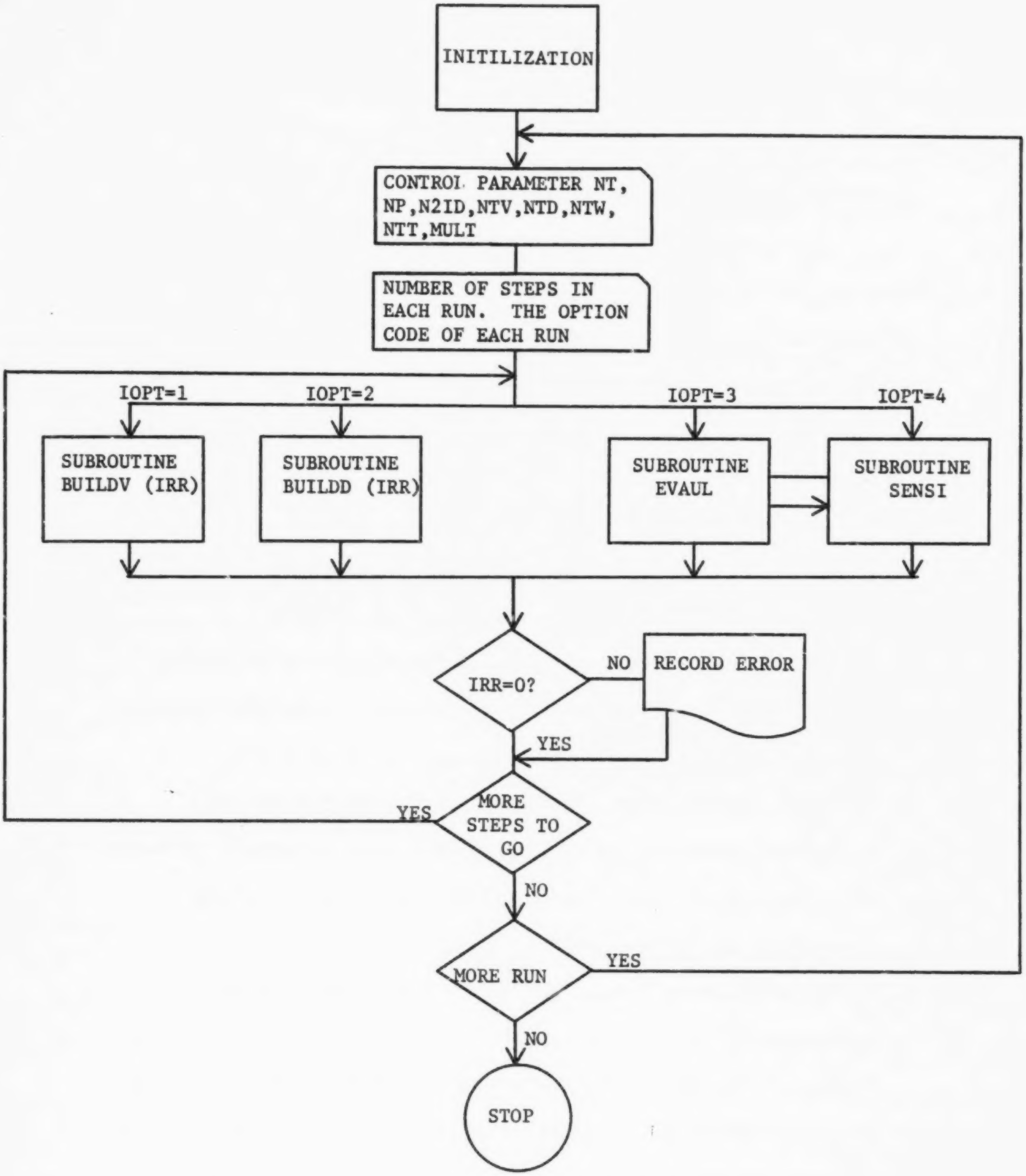
INITILIZATION
CONTROL PARAMETER NT, NP,N2ID,NTV,NTD,NTW, NTT,MULT
NUMBER OF STEPS IN EACH RUN. THE OPTION CODE OF EACH RUN
IOPT=1
IOPT=2
IOPT=3
IOPT=4
SUBROUTINE BUILDV (IRR)
SUBROUTINE BUILDD (IRR)
SUBROUTINE EVAUL
SUBROUTINE SENSI
IRR=0?
NO
RECORD ERROR
YES
YES
MORE STEPS TO GO
NO
MORE RUN
YES
NO
STOP

FIGURE 12

LOGIC FLOW OF MAIN PROGRAM

c. If the option code is equal to 2, the subroutine BUILDD is called to accept the data points collected as Datset corresponding to the parameters structured in the Valset. If requested, the Datset can be written on file.

d. If the option code is equal to 3, the subroutine EVAUL is called. Parameter by parameter data in the Datset is mapped according to the value function of the parameter in Valset, and the SVA is computed for each set of data points.

e. If the option code is equal to 4, the subroutine SENSI is called. For a given set of information (such as number of variations required, percent of variation and data points for the base value), the subroutine determines the data point on both sides of base data point for each parameter according to the given percent of variation. For example, if the variation is specified as ±10%, the subroutine would compute two new data points for each parameter. These data points would be the original data point ±10% of the range of the parameter. (The range of the parameter is the difference between the minimum and maximum data points which represent the practical limits of the parameter.) By calling subroutine EVAUL, a set of SVA's is calculated by substituting the new data points into the original Datset one at a time. Thus the variation due to each 10% change in a data point can be calculated. The program presents the results as follows:

1. $\dfrac{\text{SVA computed with positive variation - Base SVA value}}{\text{Base SVA value}} \times 100$

2. $$\frac{\text{SVA computed with negative variation - Base SVA value}}{\text{Base SVA value}} \times 100$$

3. (SVA computed with positive variation - SVA computed with negative variation) X 100

In the printout of results parameters are ranked in accordance with the absolute value of no. 3 above. The highest absolute value is ranked first. Those parameters showing the highest variations are the most sensitive ones for the data set being tested. If other basic data sets are tested the sensitivity will vary in accordance with the location of each data point on its respective value function. Those lying on steep portions of value function curves will show the greatest sensitivity.

3.0 DESCRIPTION AND FORMAT OF INPUT

Input of this program varies from run to run depending on the number of subroutines to be called. The control information (such as number of groups, parameters in each group, and so on) required by main programs is essential input. The other input such as name of the parameters, characteristics of the parameter, weights and name of the data set depends on the subroutine called in the current run. All input and the format is described in detail below.

3.1 Input for Main Program

Card	Column	Name	Description
1	1 - 2	NT	Number of groups
	3 - 4	NP(1)	Number of parameters in first group
	5 - 6	NP(2)	Number of parameters in second group
	7 - 8	N2ID	Indicator of second group 0 = addended 1 = factor
	9 - 10	NTV	Data set reference number where Valset is stored or to be stored. NTV = 5 for Valset input by cards and not to be stored.
	11 - 12	NTD	Data set reference number where Datset is stored or to be stored, NTD = 5 for Datset input by cards and not to be stored.
	13 - 14	NTW	Data set reference number where SVA value is stored, NTW = 6 for printer.
	15 - 16	NTI	Data set reference number points are stored, NTI = 5 for card input
	17 - 18	MULT	Indicator for multiple runs 1 = more data to be run 0 = for the last run.

If there is only one group (NT = 1), then the variables all move two columns (i.e., the column 5 - 6 contains N2ID, column 7 - 8 contains NTV and so on).

Card	Column	Name	Description
2	1 - 2	ITSTP	Total number of steps. A step is defined as the process to be accomplished, such as build a Valset, build Datset, or evaluate the Datset against the Valset. Maximum = ten steps per run.
	3 - 4	IOPT(1)	The option code for step 1. The options are: 1 = build a Valset, 2 = build a Datset, 3 = evaluate Datset against Valset, and 4 = sensitivity analysis.
		IOPT (ITSTP)	The option code for step ITSTP.

Format for these two cards is (20I2).

3.2 Input for Subroutine BUILDV

Card	Column	Name	Description
1	1 - 12	MOD	The name of the Valset.

Format for this card is (3A4).

Card	Column	Name	Description
2	1 - 8	PNAME	Name of the parameter
	9 - 15	PMAX	Maximum value of the parameter on x-axis-common measurement scale
	16 - 22	PMIN	Minimum value of the parameter on x-axis-common measurement scale
	23 - 29	PMAXY	The relative value corresponding to PMAX
	30 - 36	PMINY	The relative value corresponding to PMIN
	37 - 43	PCURVE	The code for the value function. Table XII lists the code and the function.
	44 - 50	PSCALE	The scale for the measurement: 0 for linear scale, and 1 for log scale
	51 - 57	PSLOPE	The slope of the curve. Leave it blank if the parameter has break points.
	58 - 64	C(I,J)	Constant for equations 19 and 20
	65 - 66	NBK	Integer, right hand adjusted number of break points for linear approximation. Maximum = 3.
	67 - 68	NF(I,J)	Normalization factor 1 = x-axis need normalization 0 = no normalization needed

Format for this card is (2A4, 8F7.0, 2I2).

Card	Column	Name	Description
3	1 - 7	BKX(I,J.1)	The coordinate on X axis for break point number one of parameter J in group I.
	8 - 14	BKY (I,J,1)	The value on Y axis corresponding to BKX (I,J,1)
	15 - 21	BKX (I,J.2)	The coordinate on X axis for break point number two of parameter J in group I.
	22 - 28	BKY (I,J,2)	The value on Y axis corresponding to BKX (I,J.3)
	29 - 35	BKX (I,J,3)	The coordinate on X axis for break point number three of parameter J in group I.

TABLE XII
VALUE FUNCTIONS

CODE	FUNCTION
1	Y = X
2	Y = -X
3	Y = A*X + B
4	Y = -A*X + B
5	Y = X** A
6	Y = 1.-X** A
7	Y = (1. - X)** A
8	Y = 1.- (1. -X)** A
9	Y = A *(1. -X)** A
10	Y = (1. - A** (1. -X)) / (1. -A)
11	Y = (A**X-A) / (1.-A)
12	Y = (1. -A**X) / (1. -A)
13	Y = 1.0 - SIN(1.5708 * X)
14	Y = COS (1.5708 * X)
15	Y = 1.0 - COS(1.5708 * X)
16	Y = SIN(1.5708 * X)
17	Y = 1.
18	Y = 0
19	Y = TANH(C*X**A)
20	Y = 1.-TANH (C*X**A)
21	Y = 1 IF X = 1 Y = 0 otherwise

NF = 1 for code 1 through 18

N = 0 for code 19 through 21

Card	Column	Name	Description
	36-42	BKY (I,J,3)	The value on Y axis corresponding to BKX (I,J,3)

Card numbers 2 and 3 are repeated for each parameter of each group. If NBK = 0 the third card should be skipped.

Format of this card is (7F7.0)

4	1 - 7	WTS(1,1)	The fractional weight of the first parameter in group 1.
	8-14	WTS(1,2)	The fractional weight of the second parameter in group 1.
	⋮		
	64 - 70	WTS(1,10)	The fractional weight of the 10th parameter in group 1.

Repeat this card for more than ten parameters in one group and weights of the parameter in second group.

Format of this card is (10F7.0).

3.3 Input for Subroutine BUILDD

Card	Column	Name	Description
1	1 - 80	DID	Name of the data set

Format for this card is (20A4).

2	1 - 7	D(1,1)	Data point for the first parameter of first group.
	.		
	.		
	.		
	64 - 70	D(1,10)	Data point for the tenth parameter of first group

Repeat this card for more than ten parameters in first group.

3	1 - 7	D(2,1)	Data point for the first parameter of second group.
	.		
	.		
	.		
	64 - 70	D(2,10)	Data point for the tenth parameter of second group.

Repeat this card for more than ten parameters in second group and omit this card if there is no second group.

Format for these two cards is (10F7.0).

3.4 Input for Subroutine SENSI

Card	Column	Name	Description
1	1 - 2	NV	Number of the percent variations to be performed, Maximum 10
	3 - 9	PCT(1)	Percent to be varied for the first variation.
	.		
	.		
	.		

Card	Column	Name	Description
	66 - 72	PCT (10)	Percent to be varied for the tenth variation.

Format of this card is (I2,10F7.0)

2	1 - 2	LGL	Scale linearization indicator LGL = 1 scale is linear and no need to linearize the scale. LGL = 2 scale is log and needs to be linearized.
	3 - 4	MID	The inidcator for choose data point to be used as base value for sensitivity analysis MID = 1 choose middle point of x-axis as data points. MID = 0 read in data points.

Format for this card is (2I2).

3	1 - 80	DID	Data set name, can be a dummy blank card.

Format for this card is (20A4)

4	1 - 7	D(1,1)	Data point for the first parameter of first group to be used as a base for sensitivity analysis.
	⋮		
	64 - 70	(D(1,10)	Data point for the tenth parameter of the first group to be used as a base for sensitivity analysis.

Repeat this card for more than ten parameters in first group.

5	1 - 7	D(2,1)	Data point for the first parameter of second group to be used as a base for sensitivity analysis.
	⋮		

Card	Column	Name	Description
	64	D(2,10)	Data point for the tenth parameter of second group to be used as a base for sensitivity analysis.

Repeat this card for more than ten parameters in second group and omit this card if there is no second group.

Format for these two cards is (10F7.0).

4.0 PROGRAM LISTING AND SAMPLE INPUT

The section shows the program listing written in Fortran IV for the IBM 360/50 series computers. At the end of the listing are sample inputs.

```
//SVAAQMN  JOB '8860 ,1040,D22',POH,CLASS=E,TIME=02,REGION=100K
//  EXEC  FORTGCG
//FORT.SYSIN  DD *
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
   15 READ(5,2)  NT, (NP(I), I=1,NT) ,N2ID, NTV, NTD, NTW,NTI,MULT
    2 FORMAT(20I2)
      READ(5, 2) ITSTP,(IOPT(I),I=1,ITSTP)
      DO 10 I=1, ITSTP
      IT=IOPT(I)
      GO TO (20,30,40,100),IT
   20 CALL BUILDV(IRR)
      GO TO 50
   30 CALL BUILDD(IRR)
      GO TO 50
   40 CALL EVAUL (EFF)
      WRITE(NTW, 5)  (DID( K),K=1,20),  EFF
    5 FORMAT(1X,20A4,F11.6)
      GO TO 50
  100 CALL SENSI
   50 IF(IRR)  10,10, 60
   60 DO  65  J=I, ITSTP
      IF( IOPT(J) - 3)  10, 70, 70
   65 CONTINUE
   70 WRITE(6,3)
    3 FORMAT(1H0 'ERROR IN VALSETS OR DATASETS, TRY AGAIN' )
   10 CONTINUE
      IF(MULT .EQ. 1) GO TO 15
      STOP
      END
      SUBROUTINE BUILDV (IRR)
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      IRR=0
      READ(5,1) (MOD(I),I=1,3)
    1 FORMAT(3A4)
      WRITE(6,102)     (MOD(I),I=1,3)
  102 FORMAT(1H1 35X,'PARAMETERS  CONSIDERED  IN  THE  MODE--',3A4
     1 ,/1H0 3X,'NAME        X-MAX        X-MIN       WEIGHT       CURVE NO',
     2 6X,'SCALE        SLOPE       NO. BK. PT.    CONSTANT  NOR-FACTOR')
      DO 20 I=1, NT
      INP=NP(I)
      DO 20 J=1, INP
      WTS(I,J)=0
      READ(5,2)           (PNAME(I,J,K),K=1,2), PMAX(I,J), PMIN(I,J),
     1PMAXY(I,J), PMINY(I,J),PCURVE(I,J), PSCALE(I,J),PSLOP(I,J),C(I,J),
     2NBK(I,J)   ,NF(I,J)
    2 FORMAT(2A4,8F7.0,2I2)
      IF(NBK(I,J) )  30, 30, 25
   25 NB=NBK(I,J)
      READ(5,3)  (BKX(I,J,K),BKY(I,J,K),K=1, NB )
    3 FORMAT(7F7.0)
      CALL SLOPE(I,J)
   30 PRANGE(I,J) = PMAX(I,J) -PMIN(I,J)
      IF(PSCALE(I,J))  20,20, 10
   10 IF(PMIN(I,J)) 15, 15, 20
   15 WRITE(6,7) ( PNAME(I,J,K),K=1,2 ),PMIN(I,J), PSCALE(I,J)
    7 FORMAT(1H0 'ERROR FOR PARAMETER ', 2A4,  2F10.2)
      IRR=1
   20 CONTINUE
      DO 60 I=1,NT
      IF(I.EQ.2.AND.N2ID.EQ.1) GO TO 60
      INP=NP(I)
      READ(5,4) (WTS(I,J), J=1,INP)
    4 FORMAT(10F7.0)
   60 CONTINUE
   40 DO 50 I=1,NT
      INP=NP(I)
      DO 50 J=1,INP
      NB=NBK(I,J)
      IF ( PSCALE(I,J)) 150,150,155
  155 WRITE(6,101 ) (PNAME(I,J,K),K=1,2),PMAX(I,J),PMIN(I,J),WTS(I,J),
     1                       PCURVE(I,J),             PSLOP(I,J),
     2NB,C(I,J),NF(I,J)
  101 FORMAT(1H0 2A4,3(2X,F10.2),F10.0,'     LOG',5X,F10.2,8X,I2,2X,
     1 E15.3,8X,I2)
      GO TO 210
  150 WRITE(6,103 ) (PNAME(I,J,K),K=1,2),PMAX(I,J),PMIN(I,J),WTS(I,J),
     1                       PCURVE(I,J),             PSLOP(I,J),
     2NB,C(I,J),NF(I,J)
  103 FORMAT(1H0 2A4,3(2X,F10.2),F10.0,'  LINEAR',5X,F10.2,8X,I2,2X,
     1 E15.3,8X,I2)
  210 IF(NB.EQ.0) GO TO 51
      WRITE(6,105) (BKX(I,J,K),BKY(I,J,K),BKSLOP(I,J,K),K=1,NB)
  105 FORMAT(  '  THE BK X, Y, AND SLOPE = ' ,3(F10.2,F5.2,F10.4)    )
   51 IF(NTV.EQ.5) GO TO 50
      WRITE(NTV, 6) (PNAME(I,J,K),K=1,2),PMAX(I,J),PMIN(I,J),WTS(I,J),
     1PMAXY(I,J),PMINY(I,J),PCURVE(I,J), PSCALE(I,J),PSLOP(I,J),
     2NB,(BKX(I,J,K),BKY(I ,J,K), BKSLOP(I,J,K),K=1,NB)
    6 FORMAT(2A4,2F10.2,3F5.2, 2F3.0, F10.4, I2, 3(F10.2,F5.2,F10.4))
   50 CONTINUE
  100 RETURN
      END
      SUBROUTINE SLOPE(I,J)
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,    NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      DIMENSION  V(3)
      M=NBK(I, J)
      DO 20 K=1,M
      CALL NORM (I, J, BKX(I,J,K), V(K) )
   20 CONTINUE
      PSLOP(I,J) = (BKY(I, J,1) - PMINY(I,J)) /(V(1)- 0.)
      GO TO ( 30,  40, 50 ), M
   30 BKSLOP(I,J,1) = (PMAXY(I,J) - BKY(I,J,1) ) / ( 1. - V(1))
      GO TO 100
   40 BKSLOP(I,J,1) = (BKY(I,J,2) - BKY(I,J,1)) / ( V(2) - V(1))
      BKSLOP(I,J,2) = (PMAXY(I,J) - BKY(I,J,2)) / ( 1. -V(2))
      GO TO 100
   50 BKSLOP(I,J,1) = (BKY(I,J,2) - BKY(I,J,1)) /( V(2) - V(1))
```

```
      BKSLOP(I,J,2) = (BKY(I,J,3) - BKY(I,J,2)) /( V(3) - V(2))
      BKSLOP(I,J,3) = (PMAXY(I,J) - BKY(I,J,3)) /( 1. - V(3))
  100 RETURN
      END
      SUBROUTINE BUILDD(IRR)
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      IRR=0
   10 READ(NTI, 5,END=500) (DID(I),I=1,20)
    5 FORMAT(20A4)
      DO 100 I=1,NT
      INP=NP(I)
      READ(NTI,6) (D(I,J),J=1,INP)
    6 FORMAT(10F7.0)
      IF(NTD.EQ.5) GO TO 100
      WRITE(NTD, 6) (D(I,J ),J=1,INP)
  100 CONTINUE
  500 RETURN
      END
      SUBROUTINE EVAUL (EFF)
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      DIMENSION YA(2)
      IRR=0
      DO 10 I=1,ITSTP
      IF(IOPT(I).EQ.1) GO TO 100
   10 CONTINUE
   20 REWIND NTV
      DO 30 I=1, NT
      INP=NP(I)
      DO 30 J=1, INP
      READ (NTV, 1) (PNAME(I,J,K),K=1,2),PMAX(I,J),PMIN(I,J),WTS(I,J),
     1PMAXY(I,J),PMINY(I,J),PCURVE(I,J), PSCALE(I,J),PSLOP(I,J),
     2NB,(BKX(I,J,K),BKY(I,J,K), BKSLOP(I,J,K),K=1,NB)
    1 FORMAT(2A4,2F10.2,3F5.2, 2F3.0, F10.4, I2, 9(F10.2,F5.2,F10.4))
      NBK(I,J)=NB
   30 CONTINUE
  101 FORMAT( 19A4,A3,11F10.2)
  100 DO 110 I=1, NT
      INP=NP(I)
      DO 110 J=1, INP
      IF(D(I,J).GE.PMIN(I,J).AND. D(I,J).LE.PMAX(I,J)) GO  TO 110
      WRITE( 6, 102 )  I, J, D(I,J), PMIN(I,J), PMAX(I,J)
  102 FORMAT(1H0 'OFF LIMITS,I, J, X ,MIN, MAX ARE=', 2I2,3F15.4)
      IF(D(I,J).LT.PMIN(I,J))  D(I,J)=PMIN(I,J)
      IF(D(I,J).GT.PMAX(I,J)) D(I,J)=PMAX(I,J)
      IRR=1
  110 CONTINUE
      EFF=1
  120 DO  500  I=1, NT
      IF(I.EQ.2 .AND. N2ID.EQ.1) GO TO 125
      YA(I)=0.
      GO TO 130
  125 YA(I)=1
  130 INP=NP(I)
      DO 490 J=1,INP
      U=D(I,J)
      CALL NORM(I,J,U,X)
      IF(NF(I,J).EQ.0) X=D(I,J)
      A=PSLOP(I,J)
      B=PMINY(I,J)
      N=PCURVE(I,J)
      IF( NBK(I,J) )   400, 400, 150
C     BREAKPOINT COMPUTATION
  150 U=BKX(I,J,1)
      CALL NORM( I, J, U, X1)
      BX=X1
      IF(X.GE. X1) GO TO 200
  160 CALL CURVE( 3,  A, B, X, Y ,C(I,J))
      GO TO 405
  200 IF(NBK(I,J).GT.1 ) GO TO  250
  230 B=BKY(I,J,1)
      A=BKSLOP(I,J,1)
      X=X-BX
      GO TO 160
  250 U=BKX(I,J,2 )
      CALL NORM(I, J, U, X1 )
      IF(X. GE. X1 )  GO  TO  270
      GO  TO 230
  270 BX=X1
      IF(NBK(I,J) .GT. 2 )  GO TO  350
  300 B=BKY(I,J,2)
      A=BKSLOP(I, J, 2 )
      X=X-BX
      GO TO 160
  350 U=BKX(I,J,3)
      CALL NORM( I, J, U, X1)
      IF(X.LT.X1 ) GO TO 300
      B=BKY(I,J,3)
      A=BKSLOP(I,J,3)
      X=X-X1
      GO TO 160
  400 CALL CURVE( N, A, B, X, Y ,C(I,J))
  405 IF(I - 1) 420, 420, 410
  410 IF(N2ID.NE.1 )  GO TO 420
      YA(I)= YA(I)*Y
      GO TO 490
  420 YA(I)= YA(I) + WTS(I,J) * Y
  490 CONTINUE
  500 CONTINUE
      DO 600 I=1,NT
      EFF=EFF*YA(I)
  600 CONTINUE
 1000 RETURN
      END
      SUBROUTINE NORM(I,J, U, X )
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),      N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      IF(PSCALE(I,J) )  10, 10, 20
```

```
   10 X =( U - PMIN(I,J)) / ( PMAX(I,J) - PMIN(I,J))
      GO TO  30
   20 X =( ALOG10( U) - ALOG10(PMIN(I,J) ))/( ALOG10(PMAX(I,J) )
     1- ALOG10(PMIN(I,J)))
   30 RETURN
      END
      SUBROUTINE CURVE(N,A,B,X,Y ,C)
      GO TO (1,2, 3, 4, 5, 6, 7, 8, 9,10,11, 12, 13, 14,15, 16,17,18,
     1 19,20,21),N
    1 Y=X
      GO TO 1000
    2 Y=-X
      GO TO 1000
    3 Y=A*X + B
      GO TO 1000
    4 Y=-A*X +B
      GO TO 1000
    5 Y=X** A
      GO TO 1000
    6 Y=1.- X** A
      GO TO 1000
    7 Y=(1. - X ) ** A
      GO TO 1000
    8 Y=1.- (1. -X ) ** A
      GO TO 1000
    9 Y=A *(1./A**X - 1.) /(1. -A)
      GO TO 1000
   10 Y=(1. - A**(1. - X) ) /(1.-A)
      GO TO 1000
   11 Y=(A**X-A) /(1.-A)
      GO TO 1000
   12 Y=(1. -A**X) /(1.-A)
      GO TO 1000
   13 Y=1.0 - SIN(1.5708 * X)
      GO TO 1000
   14 Y=COS(1.5708 * X)
      GO TO 1000
   15 Y=1.0 - COS(1.5708 * X)
      GO TO 1000
   16 Y=SIN(1.5708 * X )
      GO TO 1000
   17 Y=1.
      GO TO 1000
   18 Y=0
   19 Y=TANH(C*X**A)
      GO TO 1000
   20 Y=1.-TANH(C*X**A)
      GO TO 1000
   21 Y=0
      IF(X.EQ.1) Y=1
 1000 RETURN
      END
      SUBROUTINE SENSI
      COMMON PNAME(2,99,2),PMAX(2,99),PMIN(2,99),PCURVE(2,99),
     1PSCALE(2,99),NBK (2,99),  BKX(2,99,3),BKY(2,99,3),BKSLOP(2,99,3),
     2WTS(2,99),D(2,99),DID(20),       N2ID,NTD,NTV,     NT,NP(2)
     3 ,PMAXY(2,99),PMINY(2,99),PSLOP(2,99),PRANGE(2,99),ITSTP,
     4 IT ,NTI,NTW  ,C(2,99) ,IOPT(10),NF(2,99) ,MOD(3)
      DIMENSION SL(2) ,MM(2,99),MI(200),MJ(200)
      DIMENSION  PCT(10),DM(2,99),TS(2,99),DIF(3,2,99)
      DATA SL/'LINR','LOG '/
      READ(5, 1)  NV, (PCT(I),I=1,NV)
      IF(NV.EQ. 0)  GO TO     200
    1 FORMAT(I2,10F7.0)
   10 READ (5, 2)  LGL,  MID
    2 FORMAT( 2I2 )
      IF( MID.NE. 1)  GO TO  300
      DO 40  I=1,NT
      INP=NP(I)
      DO  25  J=1,INP
      IF( PSCALE( I, J) .EQ. 0 ) GO TO 20
      IF(LGL.EQ. 1 )  GO TO  20
      DM(I,J)=(ALCG10(PMAX(I,J))-ALOG10(PMIN(I,J)))/2.
      DM(I,J)=DM(I,J)+ALOG10(PMIN(I,J))
      DM(I,J)=10.**DM(I,J)
      GO TO 30
   20 DM(I,J) = ( PMAX(I,J) - PMIN(I,J) ) / 2.+PMIN(I,J)
   30 TS(I,J)=PSCALE(I,J)
      PSCALE(I,J) =0
      D(I, J ) = DM(I, J)
   25 CONTINUE
   40 CONTINUE
   50 CALL  EVAUL (EFF)
      WRITE(6,3) (MOD(IX),IX=1,3),SL(LGL)
    3 FORMAT(1H1    'SENSITIVITY ANALYSIS OF VALSET-',3A4,5X,'SCALE=',A4)
      WRITE(6, 4 )  EFF
    4 FORMAT( 1H0      'BASE VALUE = ', F11.6   )
      DO 55 I=1,NT
      INP=NP(I)
      WRITE(6,600) (D(I,J),J=1,INP)
  600 FORMAT(1X,' DATA FOR BASE VALUE ARE ',(10F10.2))
   55 CONTINUE
      DO 100 K=1, NV
      WRITE( 6, 5)  PCT(K)
    5 FORMAT( //1H0    'PERCENT VARIATION IS:', F8.2  // )
      DO 60 I=1, NT
      INP= NP(I)
      DO 60 J=1, INP
      MM(I,J)=0
      DV=PCT(K) * PRANGE(I,J)/100.
      D(I,J) = DM(I, J) + DV
      IF( D(I,J) .GT. PMAX(I,J))  D(I,J)=PMAX(I,J)
      CALL EVAUL(EFV1)
      D(I,J) =DM(I,J) - DV
      IF(D(I,J).LT. PMIN(I, J) )  D(I, J) =PMIN(I,J)
      CALL EVAUL(EFV2)
      DIF(3,I,J) =(EFV1 - EFV2 ) *100.
      DIF(1,I,J) =(EFV1 - EFF) * 100. /EFF
      DIF(2,I,J) =(EFV2 -EFF) * 100. /EFF
      D(I,J)=DM(I,J)
   60 CONTINUE
      IR=0
      DO 80 I=1,NT
      INP=NP(I)
      DO 80 J=1,INP
      IR=IR+1
      GG=0
      DO 70 II=1,NT
      INP1=NP(II)
      DO 70 JJ=1,INP1
      IF(MM(II,JJ).EQ.1) GO TO 70
      IF(ABS(DIF(3,II,JJ)).LT.GG) GO TO 70
      GG=ABS(DIF(3,II,JJ))
      IL=II
      JL=JJ
   70 CONTINUE
      MM(IL,JL)=1
      MJ(IR)=JL
      MI(IR)=IL
   80 CONTINUE
      WRITE(6,7)
    7 FORMAT(3X,'NAME      I    J  ORDER    PCT.  POS.      PCT.  NEG.' ,
     1 5X,'PCT. DIFF.')
      DO 90 I=1,IR
      IL=MI(I )
      JL=MJ(I )
      WRITE(6,8) (PNAME(IL,JL,L),L=1,2),IL,JL,I,(DIF(L,IL,JL),L=1,3)
    8 FORMAT(1X,2A4,2(2X,I2),3X,I3,3(3X,F12.6))
   90 CONTINUE
  100 CONTINUE
      GO TO 500
  200 NV=10
      DO 210 I=1,10
      PCT(I)=I*10
  210 CONTINUE
      GO TO 10
  300 CALL BUILDD(IRR)
      DO 310 I=1, NT
      INP=NP(I)
      DO 310 J=1,INP
      DM(I,J)=D(I,J)
  310 CONTINUE
      GO TO 50
  500 RETURN
      END
//GO.SYSABEND DD SYSOUT=A
//GO.SYSIN DD *


  SAMPLE   INPUT

 2 6 5 1 5 5 6 5 1
 2 1 4
EMISSION
SMOKE   4.6    .95           0      1      20       02.394  .05004
ODOR    5.1    .49           0      1      20       01.564  .1479
MAXNOISE84.    70.           0      1      20       023.05  105E-46
IDLNOISE69.    55.           0      1      20       018.54  192E-36
LSPNOISE 70.   56.           0      1      20       018.84  409E-37
INTNOISE66.    49.           0      1      20       020.83  608E-40
EMCO    4.6    3.3           0      1      20       012.84  747E-11
EMHC    .51    .29           0      1      20        7.048  242.4
EMNOX   .50    .34           0      1      20        10.7   3782.
EMSOX   .46    .09           0      1      20        2.394  12.39
EMPART  .076   .009          0      1      20        1.787  187.5
.20    .20    .12    .14    .20    .14
 310.    20.    30.
 1 0
 THIS IS A MIDDLE VALUE POINT TEST
2.720  2.314  78.84  63.77  64.77  59.46
4.100  .4215  .4378  .2720  .03823
 1 6 0 5 5 6 5 0
 2 1 4
RELIAB-MAINT
SYSCPX81    200      0      0      1     20       01.118  6.75E-3
ESRTSV82      1      0      1      0     19       01.938  2.269
UNSCRP83     40      0      0      1     20       01.329  1.99E-2
DSGLFE84   4800   1200      1      0     19       04.504  7.9E-17
BTWSER85     16      0      1      0     19       01.081  1.00E-1
MILEBF86  57000   8000      1      0     19       03.102  3.9E-15
.15    .1     .1     .3     .1     .25
 310.   20.    30.
 1 0
  THIS IS MIDDLE VALUE POINT
51.    .5     10.    3300.  5.     36250.
```

5.0 SAMPLE OUTPUT

The three Tables shown here are typical examples of the results printed out after a structured value/sensitivity analysis run. Tables XIII and XIV show the complete printout for a sensitivity analysis while Table XV is included to show how the input data for straight line functions are printed.

The columns shown in Tables XIII and XV are defined as follows:

NAME - An 8 character alphanumeric representation of each value function.

X-MAX,X-MIN - Many of the value functions theoretically range from 0 to infinity. However, the computer program requires practical limits for each value function. The maximum and minimum values shown are those points where the function approaches a value of 0 or 1 in a practical sense. These are subjectively selected by inspection of the plotted value functions.

WEIGHT - The A weightings assigned to each term. If a 0 is shown that function is a factor.

CURVE NO. - The number assigned to that type of function as listed in Section 3 of this appendix.

SCALE - The range of the value functions may be input on a linear or log scale as indicated.

SLOPE - The exponent, n, of the function

$$V = \text{Tanh}\ \alpha x^n \quad \text{or} \quad 1\text{-Tanh}\ \alpha x^n$$

TABLE XIII

PARAMETERS CONSIDERED IN THE MODE-EMISSION

```
                                    PARAMETERS  CONSIDERED  IN  THE  MODE--EMISSION
   NAME      X-MAX      X-MIN      WEIGHT      CURVE NO     SCALE      SLOPE      NO. BK. PT.    CONSTANT   NOR-FACTOR
 SMOKE        4.60       0.95       0.20        20.  LINEAR             2.39          0         0.500E-01       0
 ODOR         5.10       0.49       0.20        20.  LINEAR             1.56          0         0.148E 00       0
 MAXNOISE    84.00      70.00       0.12        20.  LINEAR            23.05          0         0.105E-43       0
 IDLNOISE    69.00      55.00       0.14        20.  LINEAR            18.54          0         0.192E-33       0
 LSPNOISE    70.00      56.00       0.20        20.  LINEAR            18.84          0         0.409E-34       0
 INTNOISE    66.00      49.00       0.14        20.  LINEAR            20.83          0         0.608E-37       0
 EMCO         4.60       3.30       0.0         20.  LINEAR            12.84          0         0.747E-08       0
 EMHC         0.51       0.29       0.0         20.  LINEAR             7.05          0         0.242E 03       0
 EMNOX        0.50       0.34       0.0         20.  LINEAR            10.70          0         0.378E 04       0
 EMSOX        0.46       0.09       0.0         20.  LINEAR             2.39          0         0.124E 02       0
 EMPART       0.08       0.01       0.0         20.  LINEAR             1.79          0         0.188E 03       0
```

TABLE XIV

SENSITIVITY ANALYSIS OF VALSET-EMISSION

```
SENSITIVITY ANALYSIS OF VALSET-EMISSION          SCALE=LINR

BASE VALUE =     0.015591


PERCENT VARIATION IS:    10.00

  NAME       I    J   ORDER    PCT.  POS.       PCT.  NEG.       PCT. DIFF.
EMCO         2    1      1     -35.162109       30.561569       -1.024700
EMNOX        2    3      2     -33.497696       29.366959       -0.980126
EMHC         2    2      3     -31.275192       28.099030       -0.925706
EMSOX        2    4      4     -26.459564       26.200150       -0.821020
EMPART       2    5      5     -24.983307       25.845032       -0.792467
LSPNOISE     1    5      6      -7.037911        6.038696       -0.203878
INTNOISE     1    6      7      -7.186053        5.849435       -0.203237
SMOKE        1    1      8      -5.228005        5.178307       -0.162245
ODOR         1    2      9      -4.918939        5.213264       -0.157972
IDLNOISE     1    4     10      -4.929669        4.243008       -0.143012
MAXNOISE     1    3     11      -4.259328        3.649273       -0.123303


PERCENT VARIATION IS:    20.00

  NAME       I    J   ORDER    PCT.  POS.       PCT.  NEG.       PCT. DIFF.
EMCO         2    1      1     -67.490234       53.806717       -1.891146
EMNOX        2    3      2     -64.711792       52.095535       -1.821148
EMHC         2    2      3     -60.556778       50.588120       -1.732865
EMSOX        2    4      4     -50.335358       49.664627       -1.559104
EMPART       2    5      5     -47.016190       50.249985       -1.516481
LSPNOISE     1    5      6     -13.587985       10.591991       -0.376991
INTNOISE     1    6      7     -12.342190        9.547833       -0.341288
SMOKE        1    1      8      -9.958401        9.828992       -0.308506
ODOR         1    2      9      -9.190122       10.277217       -0.303516
IDLNOISE     1    4     10      -9.495435        7.448288       -0.264170
MAXNOISE     1    3     11      -8.204502        6.392829       -0.227588


PERCENT VARIATION IS:    30.00

  NAME       I    J   ORDER    PCT.  POS.       PCT.  NEG.       PCT. DIFF.
EMCO         2    1      1     -88.702652       70.211533       -2.477638
EMNOX        2    3      2     -86.331955       68.442917       -2.413102
EMHC         2    2      3     -82.157669       67.287277       -2.330003
EMSOX        2    4      4     -69.410294       68.850845       -2.155637
EMPART       2    5      5     -64.765625       71.223129       -2.120208
LSPNOISE     1    5      6     -17.888641       13.794860       -0.493979
SMOKE        1    1      7     -13.760189       13.651256       -0.427373
ODOR         1    2      8     -12.619572       14.743584       -0.426620
INTNOISE     1    6      9     -13.848045       11.656675       -0.397645
IDLNOISE     1    4     10     -12.474370        9.705009       -0.345800
MAXNOISE     1    3     11     -10.749595        8.318022       -0.297284
```

TABLE XV

PARAMETERS CONSIDERED IN THE MODE-OPERATION PERF

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                              PARAMETERS  CONSIDERED  IN  THE  MODE--OPERATN PERF
   NAME       X-MAX       X-MIN       WEIGHT      CURVE NO      SCALE        SLOPE        NO. BK. PT.     CONSTANT   NOR-FACTOR
 START         61.00        9.00         0.06         20.  LINEAR            2.01             0         0.490E-03         0
 COLDSOAK      41.00        4.00         0.05         20.  LINEAR            1.73             0         0.308E-02         0
 STRTREL1       9.00        1.00         0.06         20.  LINEAR            2.60             0         0.827E-02         0
 FUELCSP       18.00        4.50         0.06         20.  LINEAR            2.87             0         0.490E-03         0
 CRPTRQ        56.00       24.00         0.04         20.  LINEAR            4.57             0         0.207E-07         0
 SUSIDLE       61.00       29.00         0.05         19.  LINEAR            5.19             0         0.107E-08         0
 ACCTENSC     800.00      250.00         0.07          3.  LINEAR            2.89             2         0.0               1
  THE BK X, Y, AND SLOPE =      440.00 1.00      0.0         600.00 1.00  -2.7500
 AAC2570       22.00        6.50         0.10          3.  LINEAR           10.33             2         0.0               1
  THE BK X, Y, AND SLOPE =        8.00 1.00      0.0          13.00 1.00  -1.7222
 HISPPASS    1800.00     1000.00         0.09          3.  LINEAR            8.00             2         0.0               1
  THE BK X, Y, AND SLOPE =     1100.00 1.00      0.0        1350.00 1.00  -1.7778
 CRSSPD        95.00       65.00         0.10          3.  LINEAR            2.00             2         0.0               1
  THE BK X, Y, AND SLOPE =       80.00 1.00      0.0          85.00 1.00  -3.0000
 MAXSPD       110.00       80.00         0.05          3.  LINEAR            6.00             2         0.0               1
  THE BK X, Y, AND SLOPE =       85.00 1.00      0.0          95.00 1.00  -2.0000
 SPDGRADE      11.00        0.0          0.07         20.  LINEAR            1.56             0         0.500E-01         0
 RNGURBN      255.00      160.00         0.09         19.  LINEAR            8.66             0         0.306E-20         0
 RNGCRSE      255.00      160.00         0.11         19.  LINEAR            8.66             0         0.306E-20         0
```

For straight line functions this number is the slope of the first segment.

NO.BK.PT. - The number of break points in a function composed of straight line segments. The first and last points are not counted.

CONSTANT - The α value contained in the hyperbolic tangent functions shown above. A zero entry is used for straight line functions.

NOR-FACTOR - The 1 indicates that the input data has been normalized.

THE BK X, Y, and SLOPE - For straight line functions the second line contains break point data:

X_1, Y_1 - data point and value of 1st break point
$SLOPE_1$ - slope of the line segment between first and second break points
$X_{2\frac{1}{2}}$ - data point and value of second break point.
$SLOPE_2$ - etc.

Table XIV shows the results of the structured value computation and the sensitivity analysis. The base value of the run is shown in the upper left (viz. 0.015591). The percent variation which was defined earlier in this Appendix is shown at the head of each sensitivity run. Each sensitivity run applies to only one particular set of input data. In this example data points for each value function corresponding to a value to the user of 0.5 were input. The columns are defined as follows:

NAME - Same definition as above.

I - The indicator 1 or 2 shows from which group the value function came.

J - The code number assigned to each value function by the computer.

ORDER - The rank of the value function ordered according to the highest absolute value in the last sensitivity column.

PCT.POS/PCT.NEG. - The change in the base value resulting from the indicated positive or negative variation in the input data for the particular value function listed divided by the base value. The printed values are multiplied by 100 yielding a percent reading. For example, a 10% downward variation in the input data for the value function EMCO (Carbon Monoxide Emissions) would cause a -35% change in the base value 0.015591. Similarly the positive change would be 30.6%.

PCT.DIFF. - This number is the difference between the base value computed for the positive variation minus the base value computed for the negative variation multiplied by 100. It is not really a percentage. It shows the absolute change in the base value over the ± variation selected. For example, the difference of -1.0247 for EMCO in the 10% range shows that the variation in the base value of the emissions category is 0.010247 when the input data for EMCO is varied from -10% to +10%. The positive and negative signs merely indicated the direction of the slope of the variation.

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3. W. D. Rowe, "The Application of Structured Value Analysis to Models Using Value Judgments as a Data Source," The MITRE Corporation, M70-14, March 1970.